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Hydrography of the larger springs of the Ozark region of Missouri

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HYDROGRAPHY OF THE LARGER SPRINGS
OF THE OZARK REGION OF MISSOURI

BY

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A

THESIS

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Approved by ....J B Butler....................................

Professor of Civil Engineering.

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INTRODUCTION

This thesis is based upon a study of the larger springs of the Ozark Region of Missouri and is designed to answer many requests for information about the large springs.

Special studies were made to determine the probable location and approximate area of the drainage areas of the large springs (previous writers have referred to the drainage areas as being "very large" or "enormous", apparently, without any very definite idea as to the extent of the drainage areas). The average run-off per square mile from the assumed drainage area, herein called the "spring factor", was determined for the largest springs.

A special study was made of the stream piracy from the Meramec and Black River Basins by large springs in the Current River Basin. It is the Author's belief that approximately one hundred and thirty square miles of drainage area assigned to the Meramec Basin, and approximately sixty square miles of drainage area assigned to the Black River Basin should be assigned to the Current River drainage area.

The main body of the thesis is made up of the descriptions of the various springs, with descriptions of the probable location, nature of, and extent of the drainage area of each of the larger springs.

DEFINITION OF TERMS

The volume of water flow in a stream --- the "run-off" or "discharge" --- is expressed in various terms each of which has become associated with a certain class of work. These terms may be divided into two groups --- (1) those that represent a rate of flow, as second-feet, gallons per minute, miner's inches, and discharge in second-feet per square mile, and (2) those that represent the actual quantity of water, as run-off in inches, acre-feet, and millions of cubic feet. The principal terms used in this report are "second-feet" or "(c.f.s.)", "second-feet per square mile", "run-off in inches" and "acre-feet". They may be defined as follows:

"Second-feet" is an abbreviation for "cubic-feet per second" "(c.f.s.)". A second-foot is the rate of discharge of water flowing in a channel of rectangular cross section 1 foot wide and 1 foot deep at a velocity of 1 foot per second. It is generally used as a fundamental unit from which others are computed.

"Second-feet per square mile" is the average number of cubic feet of water flowing per second from each square mile of area drained, on the assumption that the run-off is distributed uniformly both as to time and area.

"Run-off in inches" is the depth to which an area would be covered if all the water flowing from it in a given period were uniformly distributed on the surface. It is used for comparing run-off with rainfall, which is usually expressed in inches.

An "acre-foot", equivalent to 43,560 cubic feet is the quantity required to cover an acre to the depth of one foot. The term is commonly used in connection with storage reservoirs.

The following terms not in common use are here defined:

"Effective drainage area" is the effective area supplying water to a spring or group of springs. It is used to compare subsurface drainage areas with similar surface drainage areas, on the assumption that both areas have equal run-off properties.

The term "spring factor" is used to denote the run-off per square mile from the springs assumed drainage area.

FACTORS AFFECTING SURFACE & UNDERGROUND FLOW

The principal factors which affect surface flow, and ground water percolation, are precipitation, evaporation, vegetation, topography and geology.

Precipitation is the source of all stream and underground flow. The mean annual precipitation for the State of Missouri and for the three climatological sections of the State for the years 1922-1936 and that for the period 1888 to 1936 are shown in table 1, the basic data being compiled from the climatological data furnished in the yearly summary for 1936 by the United States Weather Bureau. The mean annual precipitation (1898-1932) for the different parts of the State is shown on the map on Plate 1.

MEAN ANNUAL PRECIPITATION, IN INCHES, FOR MISSOURI

Year	Average for State	Average for Northern Division (Above Mo. R.)	Average for Southwest Division (west of Jefferson City)	Average for South East Division (East of Jefferson City)
1922	39.68	37.50	41.64	39.90
1923	42.18	33.43	42.47	50.64
1924	40.03	35.28	44.39	40.41
1925	39.15	38.83	36.31	41.82
1926	42.92	42.35	43.85	42.57
1927	55.53	42.03	59.85	64.70
1928	45.88	41.22	46.01	50.40
1929	46.72	44.13	45.56	50.48
1930	31.38	26.71	34.90	32.53
1931	40.31	41.10	38.85	40.97
1932	38.24	35.88	36.74	42.09
1933	37.62	29.65	37.05	36.16
1934	35.08	30.66	34.92	39.66
1935	48.04	42.33	49.12	52.66
1936	29.42	26.48	30.03	31.73
Mean 1922-36	40.81	36.51	41.48	44.45
Mean 1888-1936	40.37	36.61	41.18	43.31

Table 1

Basic Data from "1936 Summary" U.S. Weather Bureau

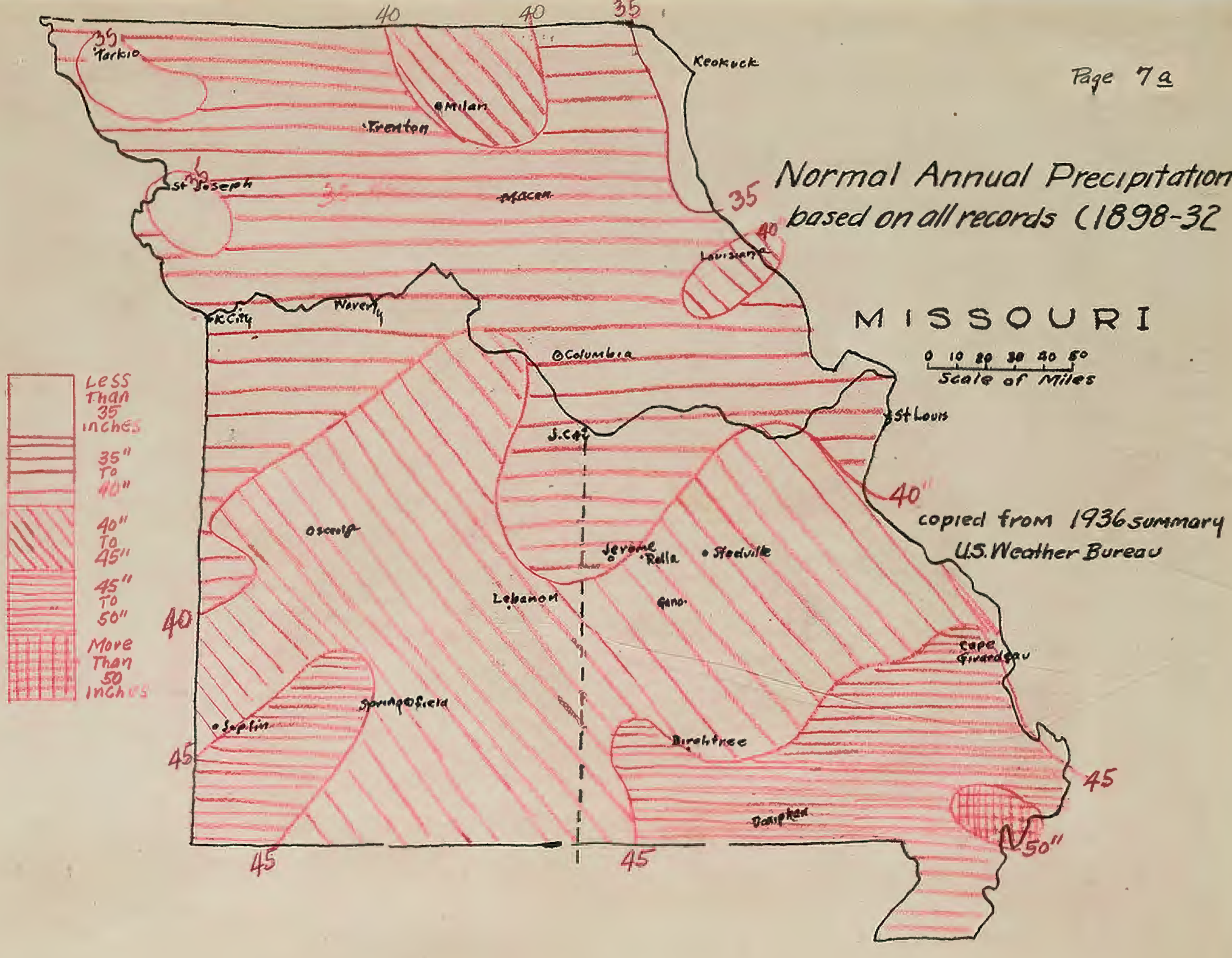

Normal Annual Precipitation
based on all records (1898-32
MISSOURI
0 10 20 30 40 50
Scale of Miles
copied from 1936 summary
U.S. Weather Bureau
Less Than 35 inches
35" To 40"
40" To 45"
45" To 50"
More Than 50 inches
Tarkio
Milan
Trenton
Keokuck
St Joseph
Macon
Louisiana
K City
Waverly
Columbia
St Louis
J. City
Osceola
Jerome
Rolla
Steelville
Lebanon
Cape Girardeau
Springfield
Joplin
Birchtree
Doniphan
35
40
40
35
35
40"
40"
40
45
45
45
45
50"

Table 1

RELATION OF RAINFALL TO RUN-OFF

It is the winter and spring rains that most largly supply the rivers and ground waters and raise the water table. The rain falling in the summer months, when vegetation is using a maximum of water and evaporation is rapid, is of little value for supplying water to the streams.[1]

The discharge of all of the large springs in the Ozark Region is markedly increased after heavy rains, although the range is much smaller than that of surface streams. The springs discharge their water much more uniformly over the year than do surface streams.

Over the fifteen year period of record at Greer Spring the maximum flow exceeds the average flow by only 260%.

Over half of the miscellaneous discharge measurements of springs were taken during the months of August and October. It is well to note that as a usual practice the springs are measured during years of very little rainfall, so that the discharge measurements usually represent the minimum flow of the springs.

During "wet" years the run-off of surface streams will probably be greater per square mile than that of the springs due to the fact that during seasons of heavy precipitation the surface streams carry the water away with great rapidity. While the springs increase in

1 Turneavure & Russel "Public Water Supply page 45

discharge, the fluctuations are not nearly so great as those of surface streams.

It is not uncommon for a surface stream of comparatively small drainage area, to have a very low flow for a long period of time; then, due to heavy rains on the water shed, to have a discharge so great that the river banks are over flowed; and then, almost as suddenly, to drop back to a very low flow. A good example of this is shown on the Cuivre River near Troy, Missouri, where, in the month of March 1923, the maximum discharge exceeded the minimum by 38,000%.

The daily discharge of the Cuivre River for the months of Oct. and Dec. 1922 and March 1923, are shown in table 2, while the hydraulic data for the hydraulic year is shown in table 3.

The drainage area above the gage near Troy is 908 square miles.

	Oct. 1922	Dec. 1922	Mar. 1923
Day	Month & Year	Month & Year	Month & Year
1	7	21	58
2	6	12	48
3	6	9	60
4	6	7	139
5	6	6	499
6	5340	5	945
7	3660	2820	1,490
8	1090	1140	693
9	653	855	395
10	177	499	303
11	85	177	613
12	64	148	22,000
13	46	121	4,740
14	42	88	1,190
15	40	62	3,140
16	33	52	6,300
17	32	42	1,720
18	21	26	980
19	20	25	613
20	18	23	463
21	16	32	412
22	16	27	363
23	15	26	289
24	14	25	249
25	13	25	236
26	13	26	199
27	12	27	167
28	11	24	157
29	11	23	139
30	10	22	139
31	10	46	114

Table 2

Daily Discharge of Cuivre River for the Months of Oct., and Dec. 1922, and March 1923

	Discharge in Second-feet				
Month 1922-23	Maximum	Minimum	Mean	Per Sq. Mile	Run-off in Inches
Oct.	5,340	6	371	.409	.47
Nov.	1,040	24	196	.716	.24
Dec.	2,820	5	208	.229	.26
Jan.	499	30	85.4	.094	.11
Feb.	1,090	23	162	.178	.19
Mar.	22,000	48	1580	1.74	2.01
Apr.	2,260	74	370	.407	.45
May	855	56	121	.133	.15
June	3,060	26	279	.307	.34
July	613	10	103	.113	.13
Aug.	18,000	10	1990	2.19	2.52
Sept.	2,660	30	235	.259	.29
The Year	22,000	5	475	.523	7.16

Table 3

Hydraulic Data on Cuivre River for Hydraulic year 1923

GEOLOGY OF THE OZARK REGION

The Ozark Region is essentially a structural dome with a northeast - southwest elongation and is thought to resemble somewhat a mammoth wash board with the corrigations roughly paralleling the main uplift.

The Ozark-St. Francis dome varies greatly in altitude and geology. The St. Francis Mountains are made up of algonkian granite and hard impervious igneous rocks known as porphyry, and reach a maximum altitude of about 1800 feet above mean sea level.

The greater portion of the Ozark Region is underlain by combrian and ordorician age rocks and consists chiefly of alternate layers of cherty, dolometic rocks of limestone, and sandstone.

The rocks dip gently in every direction from the elongated axis. Erosion has cut deep valleys, especially on the eastern side.

The two highest peaks are "Taum Sauk" (elev. 1800 feet above mean sea level) in the St. Francis Mountains and Cedar Gap in Wright County (elev. 1700 feet above mean sea level).

Structurally this area is somewhat complex, divergent anticlines merging into the main fold. There is strong evidence of two distinct periods of elevation.[1]

This is preeminently a district of great springs and caverns. In the St. Francis region however springs in the crystal-

1 Shephard, E. M., Underground Waters of Eastern United States U. S. Geological Survey W. SP 114 page 216-17

line rocks are extremely rare. The most prominent water bearing horizon, in the Ozark Region, is the Gasconade limestone (third magnesium). This formation has a maximum thickness of 500 feet -- is frequently cavernous, and some of the largest springs in the country flow from it.

Mc Queen[1] estimates that 80% of the springs in the Ozark Region flow from this formation.

As would be expected, great caves and enormous sink holes abound, the latter marking the course of underground channels. "Grand Gulf" is a large sink hole ¾ mile long and 200 feet deep. From the bottom of this chasm a cave leads into a more recent channel exposing the stream; which flows out as Mammoth Spring.

The springs that are described, with the exception of Meramec and Boiling Spring, are situated on the south flank of the Ozark uplift where a long structural slope opens the way for an important underground circulation, fed from a central table land.

The springs are in canyons where the streams have cut down into the rocks and intersect some water bearing horizon.

The central highland around Salem and vicinity is plentifully dotted with shallow pit mines, the minerals of which appear to have been deposited by the actions of the underground water. These mines as well as sinks and caves tend to mark the main channels of underground waters.

1 Mc Queen, H.S., personal statement.

According to available information, the Ozark Region, contains seven springs which have average discharges ranging from 100 cfs to several hundred cfs and therefore rank with the very large springs of the country, although not quite equaling the largest spring in Florida or the largest group of springs in the area of volcanic rock in the northwest section of the United States.

RELATION OF GEOLOGY TO SPRINGS

An inspection of topographic maps of the Ozark Region will show that "above" most of the large springs there is usually a scarcity of surface drainage. Valleys that for size and extent one would expect to have permanent surface streams, have practically no surface drainage indicated, or only dry washes or "wet weather" streams exist.

Schlichter[1] points out the fact that the underground drainage follows the surface drainage in general, and the direction taken by the surface waters is, in general, the direction taken by the underground seepage flows. The gradients for the underground waters are usually much less than that of the surface waters.

Schlichter goes on to state that the surface divide or water shed, in general, coincides with the lines of the underground divide or watershed, and the motion of the ground water seepage into springs and rivers is similar to that of surface drainage in the same stream. The similarity of the underground contours to the surface contours enables one to sketch approximately the lines of underground seepage from a contour map of the surface (the similarty between the surface and underground contours must not be taken too literally).

Meinzer[2] states that in the relation of large springs to topography, kind of rock and rock structure, the occurrence of large

1 Schlichter, Chas. S., "A Study of Missouri Springs" U. S. Geological Survey W.R. 67 1902 page 32-33

2 Meinzer, Oscar E. "Large Springs in the U.S." U.S.G.S. Water Supply paper 557 1927, page 6

springs depends chiefly on the kind of rock that yields the water. Limestone and extrusive volcanic rock are the main sources of very large springs. The limestone must contain large solution channels produced by long continued circulation of ground waters. In order that a spring flow with considerable volume, it is necessary that the water-bearing material be of a very open, porous character,

Practically all of the larger springs in the Ozark Region come from the readily soluble Gasconade limestone formation.

Sedimentary rocks are usually laid down like shingles on a roof in the following order: sandstone, which, before cementing took place, was sand, and is usually the most pervious to water, of the sedimentary rocks; second in order is shale, which, before solidification took place, was mud, and, being composed of very small particles, closely united, is usually an impervious stratum; the third in order is limestone, which, before solidification, was a limey ooze, and, if unfissured, tends to be impervious --- however, it is usually fissured and is usually readily soluble by the slightly acid waters percolating through these fissures. These percolating waters very often dissolve large solution channels in the limestone. When dissolved, the limestone tends to become quite porous, and, in such condition, forms one of the best of water-bearing stratums. The rain water dissolves carbon dioxide gas which forms a weak acid that greatly aids in its solvent action on the rocks with which the water comes in contact.

The ground water dissolves passageways for itself through the limestone, forming numerous caves and solution channels. In this way an underground drainage net is formed that may be nearly as complicated and extensive as the drainage above ground. Some of the underground passages collect water from a wide area. The accretions of these passages form subterranean rivers (Mammoth Spring, Big Spring, Onandoga Spring, are examples where the subterranean stream may be seen long before it emerges at the surface as a spring). With the increasing dissection of the surface, the underground drainage suffers readjustment, and former channels are abandoned, appearing here and there on hillsides as dry caves.

McQueen[1] states that probably 80% of the springs of southern Missouri issue from the Gasconade formation, which formation has been described[2] as the great limestone series lying beneath the Roubidoux sandstone, with an average thickness in the central Ozark Region of between 200 and 220 feet. This thickness is fairly constant over the wes ern portion of the Eminence quadrangle (central Ozarks) where the formation is protected by a thick cap of Roubidoux sandstone. To the east of the porphyry knobs, in the Eminence quadrangle, the Gasconade formation is much thinner, although still capped in many places by a few feet of the overly'ng formation. This thinning has been caused by the removal of the soluble portions

1 McQueen, H.S., Assist. Geol. of Mo. personal communication
2 Bridge, Josiah, "Geology of the Eminence and Cardareva Quadrangles"

of the formation by circulation ground waters, and in some instances, as much as two thirds of the original thickness appears to have been removed in this manner.

The Gasconade formation is especially honey-combed by such abandoned passages.[1] As the dolomites are readily soluble in water (note the numerous caves and sinks in the Ozarks) often it can be noted where the spring mouth formerly was, high up on the hillside in a cave that is now "dry". This opening has been abandoned because as the stream eroded its way downward, the underground waters have dissolved away the rocks, forming a new outlet at a lower level. Sometimes the new opening is almost directly below the former opening, while sometimes it is laterally quite a distance away.[2]

Greer spring is a good example of this transition still taking place. In recent times, geologically speaking, the upper outlet very probably carried all the flow of the spring, but, as the channel eroded, the underground waters dissolved a solution channel along some fault or fold at a lower level, and the lower outlet was formed. As more and more water passed along this new underground channel, solution took place more rapidly, until at the present time the greater percentage of water at the spring

1 Geo. Ozark page 18 Mo. G.S. 2nd series Vol. 24 page 109
2 Groshkopf, John, Geologist of Mo. Geological Survey, personal communication

issues forth at the lower opening. The upper cave now flows only after heavy rains on the spring's drainage area. The continued solution taking place in the lower outlet will in time completely rob the upper outlet of all its water, and another "dry" cave will be formed.

The large number of springs in the Ozark Region implies a well developed system of subterranean drainage.

THE EFFECT OF SOLUBILITY OF ROCKS UPON UNDERGROUND DRAINAGE

Because the Ozarks are largely made up of limestone, solution has been an important factor in the removal of rock material. It is impossible to evaluate the relative importance of corrosion and of solution in developing the present surface. The face, however, that the limestone pebbles are rare on many Ozark streams, although limestone is the most common rock of the region, indicates the great importance of solution in the erosive process.

The extreme clearness of Ozark streams is due in part to the fact that much of the water has come from underground sources, and has not had the opportunity to gather debris. Solution is retarded in some sections by (1) the presence of massive beds of chert underground, blocking the passage of water, and (2) by the extensive dissection of parts of the region which has destroyed the continuity of many underground drainage channels and lowered the water table.

The large, undissected areas of the central Ozarks and of the western flank furnish the best condition for the collection of underground water and for solution.

Underground Water in Limestone

The waters of limestone occur mainly in open channels, caverns, etc., dissolved in the rock by the water itself. The water originally followed joint or bedding planes, which were gradually enlarged by solution into the caverns which we now find. The occurrence of caverns and passages in limestone is very irregular, and their location can seldom be predicted. Most deep wells, however, which are drilled in limestone regions encounter one or more such passages at a relatively slight distance from the surface.

The waters are generally hard.

There is, however, a considerable liklihood of pollution, due to the fact that much of the water of the underground streams in the limestone has found its way downward through sink holes, carrying with it more or less surface wash.

Underground Waters in Sandstone

Sandstone is, on the whole, the best water bearer of the solid rocks. Under the most favorable conditions the rock is saturated throughout its extent below the regular ground water level.

The water is yielded freely in most cases.

Fluctuation of Large Springs

Fluctuation in discharge is due almost entirely to varibility in precipitation, atmospheric temperature, and other weather conditions. The amount of fluctuation is, however, affected by the topography, the rock structure, and especially the kind of rock, the last of which determines chiefly the size and character of the openings through which the ground water passes. Springs in limestone are notably variable in their discharge, being much greater and more sudden than the large springs in volcanic rock.

Springs Flowing in Definite Underground Channels

In limestone, and other soluble rock the underground passages are often many miles in length. Single passages, as in Mammouth Cave in Ky., have been traversed for a distance of nearly ten miles, while passages as yet undiscovered but several times as long probably exist. Some of these passages are many feet in diameter, and are traversed by streams of considerable size. The channels of limestone springs do not ordinarily extend much below the level of the surrounding surface drainage.

Quality of Water of Large Springs

As a rule the water is not highly mineralized and even in the large limestone springs the water is only moderately hard. For to produce such large springs the water must flow rapidly through large openings and hence is not brought in very intimate contact with the rock. The mineral matter that is dissolved becomes diluted by the great volume of water.

SCENIC BEAUTY OF THE OZARK REGION

The Ozark Region has long been known for its many scenic beauties. Until recent years it has been almost inaccessible, to the motoring public, due to the lack of good roads. Now one may travel around the region on good all weather roads.

If one feels the exploring urge, all he needs to do is to turn off the main highways and drive for a mile or two, abandon the car, and tramp the hills and dales of this rugged and wooded wonderland.

There are many state parks where camping facilities are maintained. Every effort has been made to preserve the rugged natural beauty of the Ozarks.

The rivers, being spring fed, are exceptionally clear and are well stocked with members of the finny tribe, by the state fish hatcheries located at several of the large springs.

Float trips on the clear streams are particularly enjoyable, and, for a nominal price per day, the tourist will be furnished with boat, fishing tackle, tents, and a guide to cook, point out points of interest and even catch fish for him if he does not wish to do so himself. Many people from the more populated sections spend their vacations in this manner.

ROADS

Great improvement in the road net throughout the Ozark Region has been made within the past five years. Several national highways bisect the region. State routes are well maintained and have wide right-of-ways, The surfacing is generally of "black top" on the main state routes, with gravel predominating on the side roads. The state has put through many special roads that lead to the large springs, state parks, and other spots of especial scenic beauty.

The U. S. Forest Service has built and maintains many roads and fire trails through the national forests.

A circuit of less than 500 miles over all weather roads starting at Rolla, Mo., at the junction of U. S. 63 and 66, will take one to most of the largest springs in the Ozarks as well as through much of the rugged beauty of the Ozark Region. If a shorter trip is desired, a round trip of less than three hundred miles from Rolla will take one to eight of the largest, most easily accessible springs in the Ozarks,--- Meramec, Montauk, Welch, Round, Alley, Blue, Big and Greer springs.

UNDERGROUND WATERS, THEIR SOURCE, ORIGIN, AND RELATION TO SPRINGS

Rainfall is removed from the surface of the ground in three principal ways:

1. By evaporation.
2. By run-off through surface streams.
3. By absorption into rocks and unconsolidated deposits.

The third item is the one that concerns the studies of springs and underground waters.

The rainfall that is not removed by evaporation or surface drainage is absorbed by the soil or rocks with which it comes in contact, either directly, or after being gathered into streams. Absorption takes place directly and indirectly. In the case of direct absorption, the rain falls on the surface of the rock, and the water is absorbed either by its pores or by the fissures or cavities which it may contain. In indirect absorption, the water is first absorbed directly into loose, unconsolidated deposits overlying the solid rock, or is gathered into streams flowing over their surfaces. In those cases where the rocks are directly exposed to the rainfall, the water which is not immediately absorbed runs off, and either enters loose unconsolidated materials, or is gathered into streams as pointed out previously. The unconsolidated material soon becomes saturated to a certain level, and the rocks upon which it lies are in this way kept constantly in contact with the water, which is continually absorbed.

The relative amount of water indirectly absorbed by the rocks is far greater than that directly absorbed through rainfall.[1]

In direct absorption, water finds ready entrance into the larger faults, especially where the faulting movement of the two faces has caused the rocks to be crushed. (This type of fault would act like a gravel filter.) Joints, which are like small faults, often accommodate considerable amounts of water.

One of the most important ways in which waters enter the ground in the Ozarks is through the channels dissolved in the rocks themselves, known as solution channels. If solution continues long enough, part of the roof of an underground passage may collapse, causing a "sink" or "sink hole". In sinks there is no direct opening into the underground channel; in a "sink hole" there is a direct opening. There are numerous sinks and sink holes in the Ozarks, and in some cases water enters the ground in definite streams through the sink or sink hole. A connection is frequently maintained through these sinks between the surface and the underground channels, and the water falling on the surface flows into them, and passes downward to join the underground supplies.

Where the water is directly absorbed in the porous strata of rock, the amount of absorption depends largely upon the inclination of the porous beds, the amount being much greater in

1 Shepard, E.M., "Underground Waters of Eastern United States" U.S.G.S. Water Supply paper 114, page 21-28

the gently inclined beds than in those having steep dips.

The area C.D. is several times as great as A.B. though the thickness of the layer is the same, as shown in Fig. 1.

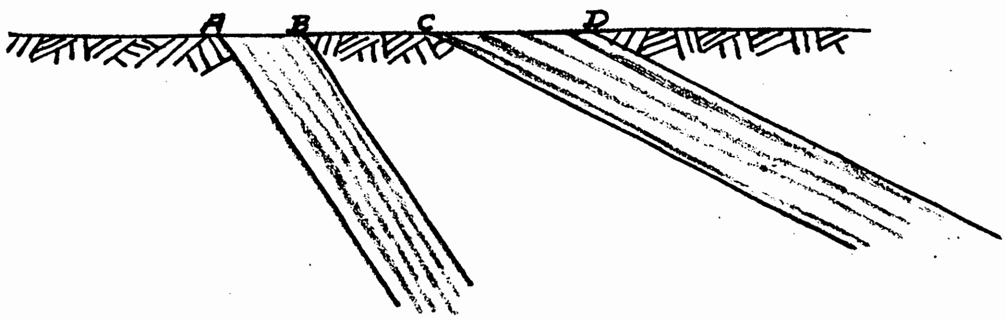


Fig. 1 showing difference in area exposed due to difference in the dips of the strata

UNDERGROUND STORAGE

Practically all writers on underground waters point out the vastness of the capacity of the underground storage of ground water. It has been estimated that the lowest limit at which ground water can exist is approximately six miles, for below this depth the pressure on the rocks is so great that the rocks "flow", and therefore there are no cracks or fissures. Schlichter[1] estimates, on the basis of average porosity of rocks and porous materials forming the earth's crust, that the total ground water of the world is about 565,000 million cubic yards, or nearly one third the total amount estimated to be in the oceans. This amount of water, he states, would cover the entire surface of the globe to a depth of between 3,000 and 3,500 feet.

Even if the above estimate were true, we do not have to deal with such enormous quantities of water in the studies of the springs of Missouri, for practically all of the springs in the Ozarks are of relatively shallow origin--as may be noted from the fact that the average temperatures of all of the springs range from 55° to 60° (which figure is approximately the mean average surface temperature for this region). It is known that for underground waters flowing less than 50 feet under the surface of the ground the temperature will vary with the seasons, while if they flow from 50 to 200 feet under the ground surface, they are unaffected by

1 Schlichter, Chas., previous citation page 13 and 14

seasonal changes, and tend to become the temperature of the mean yearly temperature of the region. If the underground waters flow at greater depths than 200 feet below the surface, the waters raise 1° in temperature for each 50 to 75 feet in depth below the 200 foot level. Therefore, all of the Ozark springs are of shallow origin as they remain at a nearly constant temperature, which approximates the mean temperature for the region.

If the total underground waters underlying the Ozark Region were considered as a giant reservoir held back by an impervious dam (similar to the Lake of the Ozarks, held back by Bagnell dam) and that this dam had only outlets, relatively, a few feet below the crest of the dam, then the only water flowing from this reservoir would be that water above the outlets. The water below the outlets would, it is true, be in storage, but to use it one would have to resort to pumping, which is exactly what is done when wells are driven or sunk below the levels of the ground water table. The water table levels are controlled by the outlets not far below the surface of the dam, which outlets are the springs. The springs control the height of the water table in the Ozark Region. (see Plate 7)

McQueen[1] points out in the above mentioned chart, and also in his statement on "Mammoth Springs" (see description of "Mammoth Spring") that this spring controls the regional ground

1 McQueen, H.S., from unpublished notes.

water level as far away as Willow Springs, Mo. (A straight line distance of 43 miles from the mouth of the spring).

WHAT IS A LARGE SPRING

In some localities having a lot of small springs, one spring having a flow of say 10 cu. ft. per second would be considered a large spring, and in many other parts of the country a spring having a discharge of one cu. ft. per second is considered a large spring.

In the U.S. there are approximately 65 springs with an average flow of 100 cu. ft. per second. Several of these large springs or groups of springs have an average discharge of over 500 c.f.s.[1] The large springs are conveniently classified as follows:

Magnitude	Average Discharge
First	100 c.f.s. or more
Second	10 c.f.s. to 100 c.f.s.
Third	1 c.f.s. to 10 c.f.s.
Fourth	100 gal. per minute to 1 c.f.s.

Springs of the first magnitude (100 c.f.s. and over, average flow) occur in several regions in the United States.

The Ozark Region, according to Meinzer,[1] ranks third in the number of springs of the first magnitude. However, according to Bolon,[2] there are approximately twelve springs in the Ozark Region

1 Meinzer, O.E., "Large Springs in the United States" U.S.G.S. w.s.p. 557 page 2-3
2 Bolon, H.C., Missouri School of Mines Thesis 1935

having discharges of 100 c.f.s. or more which would probably bring the Ozark Region up to second place. According to previous classification, the Ozark Region is exceeded first, by the Snake River basin of Utah, and second, by the Florida and southern Georgia section.

As a humorous comparison, most of the writers in general works on water supply or underground waters, cite springs that flow less than 10 c.f.s. (and term them large, too). Usually the springs mentioned are of only 1 or 2 c.f.s.

In this region of truly large springs, a spring having a discharge of one or two c.f.s. is considered a small spring (Onondaga Spring, near Leasburg, Mo., on Dec. 30, 1937 had a measured flow of 1.30 c.f.s. or, using smaller units, 840,000 gallons per day).

The rank of the larger springs in Missouri is given in Table 5

The springs of the first, second, and even the third magnitudes do discharge tremendous quantities of water. Big Spring, near Van Buren, Mo., with an average discharge of 465 cubic feet per second will discharge 300 million gallons during one twenty-four hour period, or enough water to fill a tank with a cross section of ten acres to a depth of 90 feet during a twenty-four hour period.

Meramec Spring (7th largest in the Ozark Region) near St. James, Mo., with an average discharge of 142 c.f.s. could supply a population of 917,000 people, allowing 100 gallons per day per capita. The population of St. Louis proper (1930 census) is given as 622,000.

From a study of 3356 installations of water supplies in cities of the United States (1898)[1] 54% of all installations were from ground water sources, while 502, or 15% were from springs. A similar study on water supplies for cities of 5000 population or over in France (1909) showed that 255 out of a total of 595 cities, or 43%, used springs as their source of water supply. From these and similar studies, it is shown that springs play an important part in furnishing water to city dwellers in our own country, and abroad.

1 Turneaure & Russel "Public Water Supply" 1924 page 39

STREAM PIRACY BY LARGE SPRINGS

If I pour a barrel of water on a roof, I would expect to collect approximately a barrel of water under the downspout. Now if I only collected, say, two thirds of a barrel at the downspout, I could reasonably expect to find a leak, or leaks, in the roof whereby a third of a barrel of water had leaked through. Now, if I put a pan under the leak in the roof, and catch one third of a barrel of water, then I could say thay I knew why I had not collected a full barrel at the downspout.

In a similar manner, if a certain amount of rain fell on the roof (basin) of a river, then I could expect a certain run-off from that roof down the downspout (river). If I did not find that quantity, then it would be logical to look for leaks in the roof. I find these leaks in the roof appearing as large springs.

From the surface drainage map of Missouri I find that the "leaks" in the roof of the Meramec basin and the Black River basin are appearing as large springs in the Current River basin close to the boundaries of the two above mentioned basins. It is also found that a "barrel of water" on the Current River roof, produces "one and one third barrels" at the downspout. Therefore, it appears logical that part of the water falling on the Meramec River basin and the Black River basin is finding its way into the Current River basin, and as such shows up as large springs, which greatly increases the run-off per square mile of the Current River basin.

Plate 2 was plotted showing the run-off per square mile at the various river discharge stations for a 15 year period (1922-1936).

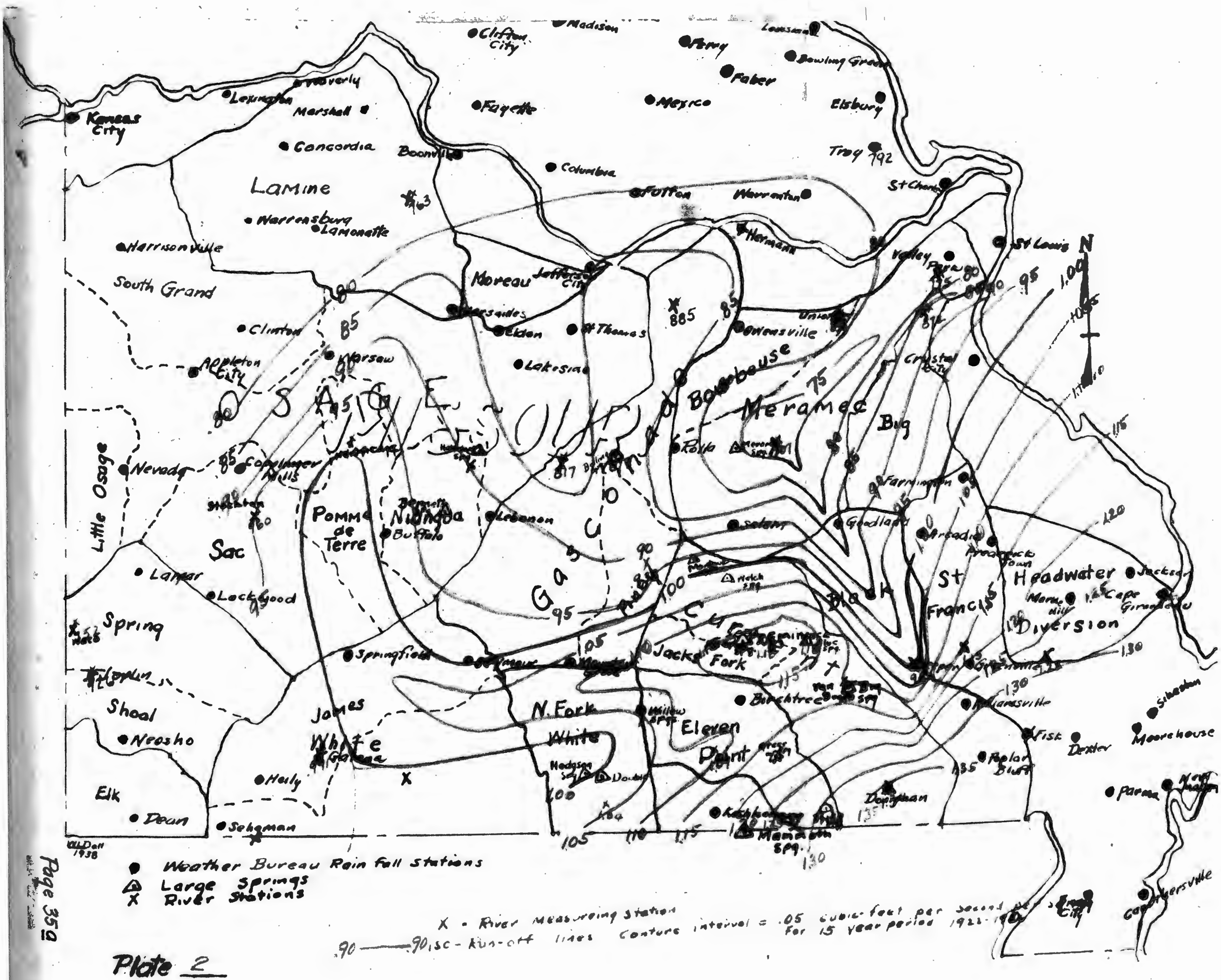

Kansas City
Lexington
Waverly
Marshall
Concordia
Boonville
Fayette
Columbia
Mexico
Perry
Faber
Bowling Green
Elsbury
Troy
St Charles
Fulton
Warrenton
Hermann
St Louis
Lamine
Warrensburg
Lamonette
Harrisonville
South Grand
Moreau
Jefferson City
Versailles
Eldon
St Thomas
Lakeside
Owensville
Union
Crystal City
Clinton
Appleton City
Warsaw
O S A G E
Bourbeuse
Meramec
Big
Rolla
Farmington
Arcadia
Little Osage
Nevada
Caplinger Mills
Pomme de Terre
Niangua
Buffalo
Lebanon
Gasconade
Salem
Sac
Lamar
Lockwood
Spring
Springfield
Jacks Fork
Black
St Francis
Headwater
Diversion
Cape Girardeau
Shoal
Neosho
James
White
Galena
N. Fork
White
Willow Spg.
Eleven Point
Birchtree
Williamsville
Dexter
Poplar Bluff
Doniphan
Mammoth Spg.
Elk
Dean
Seligman
Parma
Moorehouse
Caruthersville
Weather Bureau Rain Fall Stations
Large Springs
River Stations
X - River Measureing station
.90 ——— .90 isc - Run-off lines Conture interval = .05 cubic feet per second per sq. mi. for 15 year period
Page 35a

Plate 2

HYDRAULIC DATA OF RIVERS IN THE OZARK REGION

River	Town nearest Location	Years of Record	No. Years	Drainage Area (Sq.Mi.)	Mean Discharge (c.f.s.) for period of Record	Run-off per Sq. Mi. (c.f.s.)
Alley Spring	Alley	1930-37	7		107	
Big River	Byrnesville	1923-1936	14	892	777	.872
Big Spring	Van Buren	1922-1936	15			
Black River	Leeper	1922-1936	15	957	941	.984
Bourbeuse River	Union	1922-1936	15	767	643	.838
Castor River	Zalma	1922-1936	15	395	504	1.28
Cuivre River	Troy	1923-1936	14	908	720	.792
Current River	Doniphan	1922-1936	15	2030	2753	1.36
Current River	Eminence	1922-1936	15	1230	1449	1.18
Current River	Van Buren	1922-1936	15	1640	1829	1.11
Eleven Point River	Bardley	1922-1936	15	690	755	1.09
Gasconade River	Jerome	1924-1936	13	2840	2486	.877
Gasconade River	Waynesville	1922-1936	15	1680	1371	.817
Greer Spring	Greer	1923-1936	14		345	
Jacks Fork River	Eminence	1922-1936	15	376	443	1.18

Table 4

HYDRAULIC DATA OF RIVERS IN THE OZARK REGION

River	Town nearest Location	Years of Record	No. Years	Drainage Area (Sq.Mi.)	Mean Discharge (c.f.s.) for Period of Record	Run-off per Sq. Mi. (c.f.s.)
James River	Galena	1923-1936	14	1000	991	.991
Lamine River	Clifton City	1923-1936	14	598	456	.763
Meramec River	Eureka	1922-1936	15	3800	2942	.775
Meramec River	Steelville	1924-1936	13	830	586	.707
Meramec Spring	St. James	1922-1929	8		151	
North Fork White R.	Tecumseh	1923-1937	14	1180	1230	1.04
Piney River	Big Piney	1922-1936	15	560	526	.939
Pomme de Terre R.	Hermitage	1922-1936	15	630	632	1.00
Sac River	Stockton	1922-1936	15	1160	1114	.960
Shoal Creek	Joplin	1925-1936	12	458	424	.926
Spring River	Waco	1925-1936	12	1160	872	.752
St. Francis River	Fisk	1928-1936	9	1370	1360	.993
St. Francis River	Patterson	1922-1936	15	956	1100	1.15
White River	Beaver, Ark.	1924-1936	13	1270	1654	1.30

Table 4 (Continued)

A comparison of plate 1 with plate 2 will show that the iso-run-off lines do not follow the shape of the lines of equal run-off, in the region between Meramec Spring and Leeper. The iso-run-off lines dip sharply to the south east, forming a "valley" of low run-off, where as the lines of equal rainfall have an inclination to the north east. This condition is unnatural and shows that water is being diverted from the drainage areas of the Meramec River and the Black River into the Current River.

In order to obtain a true value of the run-off of the various drainage basins it is necessary to subtract the areas, assigned to the Meramec and Black River basins, from which water is being discharged into the Current River and add these areas to the Current River drainage area.

It is believed that Welch, and Montauk Springs are receiving water from the Meramec River Basin, while Blue Spring in Shannon County is receiving water from the Black River Basin. A more complete description of these springs is given in the "Description of Springs".

The combined drainage areas of Welch Spring and Montauk Spring are about 290 square miles.

The drainage area of Blue Spring is about 140 square miles.

Now, if the Meramec River at Steelville had its drainage area decreased enough to bring its run-off per square mile up to .84 c.f.s. (which from an inspection of the iso-run-off map appears logical), then its area would be 586 ÷ .84 or equal to 698 sq. mi. or a difference of 830 - 700 = 150 sq. mi. Likewise, if the Black River Basin above Leeper, Missouri, were decreased so that its run-off per sq. mi. were increased to 1.05 c.f.s. per sq. mi., then its area would be 941 ÷ 1.05 or equal to 896 sq. mi. or, a decrease in area equal to 957 - 896 = 61 sq. mi. or, roughly, 60 sq. mi. This would give a total decrease in the drainage area of the two basins of 130 plus 60 or 190 sq. mi.

Now, if the above mentioned 190 sq. mi. were added to the drainage area above Eminence, it would bring the total drainage area above that station to 1230 plus 190 or 1420 sq. mi. thereby making the run-off per sq. mi. at that station $= \frac{1449}{1420} = 1.03$ c.f.s. per sq. mi. This figure looks more nearly in line with the rest of the run-offs per sq. mi. of neighboring basins and also fits in very nicely with the rainfall throughout that section of the country.

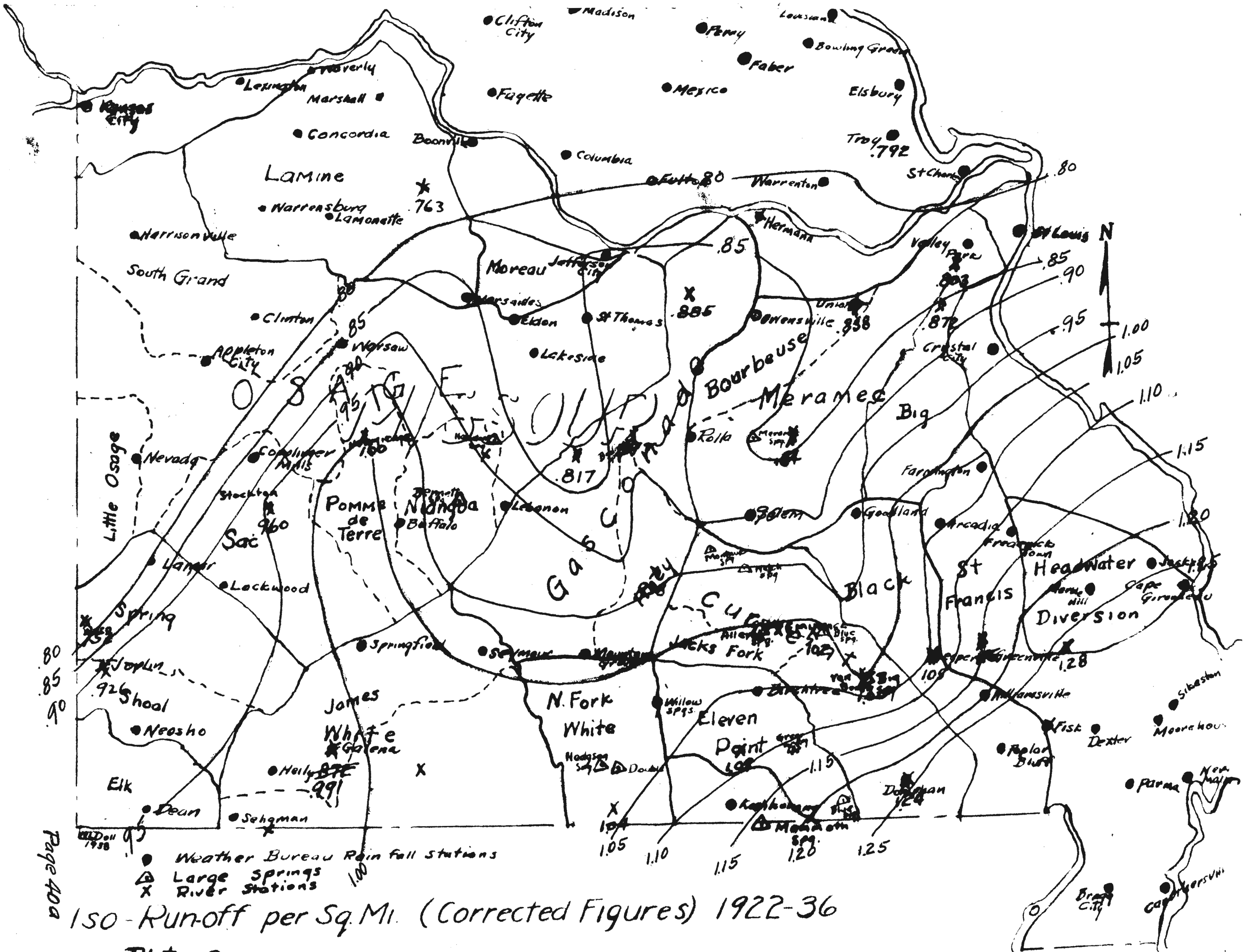
The corrected run-off per sq. mi. for the following stations is as shown:

Current River at Van Buren, Mo., $\frac{1829}{1640 + 190} = 1.00$

Current River at Doniphan, Mo., $\frac{2753}{2030 + 190} = 1.24$

Meramec River at Eureka, Mo., $\frac{2942}{3800 - 130} = .803$

From an inspection of the map showing the geology of



- ● Weather Bureau Rain fall stations
- △ Large Springs
- X River Stations

Iso-Run-off per Sq. Mi. (Corrected Figures) 1922-36

Plate 3

Missouri, it is found that the Roubidoux formation has its highest point in the great Ozark plateau (Salem and vicinity) and slopes downward in all directions from this plateau.

There are numerous caves and sinks in this formation. It, therefore, seems highly probable that this formation, acting as aquifer, or water bearing stratum, may be transporting the underground waters from this point (Salem and vicinity) and discharging the waters where the streams have cut through this formation into those of an older order.

There is a possibility this aquifer may also transport water to the Joplin artesian basin, which would explain why the run-off of Shoal Creek at Joplin (.926) is higher than the run-off for its neighboring basin, that of Spring River near Waco, Mo. (.752 c.f.s. per sq. mi.).

Plate 3 was constructed by using the corrected values as determined in the preceding pages, in conjunction with the table of hydraulic data (table 5) of the 15 year period of records on surface streams.

An inspection of this new plate when superimposed over the map of rainfall of Missouri for the past 35 years, shows a marked tendency to follow very closely, especially in the Eastern Ozark Region, the lines of equal rainfall. Therefore it would seem logical that the basin receiving the most rainfall would have the largest run-off, other things being equal.

In the north central part of the Ozarks, and also in the southwest central part, the lines of equal run-off tend to deviate from the isohyetal[1] lines by some distance. This is due, in part, to the fact that some of the points in the northern part of the state were picked across the Osage Basin, and other points were left out of this study because the drainage basins had areas too large to be comparable with the basins selected.

Likewise, in the southwestern portion of the Ozarks, the White River Basin was omitted as a large portion of its drainage area lies in Arkansas. Also, the length of record is not comparable to those stations selected.

However, since practically all the large springs are located in the southeastern section of the Ozark Region, the above mentioned deviation is not considered serious.

Proceeding on the assumption that over a long period of time (15 years), adjacent small areas in the same basin receiving similar amounts of rainfall per square mile, would tend to have the same run-off, other things being equal.

I contend that the run-off for a spring's <u>effective</u> drainage area will be comparable to that of adjacent surface tracts of similar area, considered over a number of both wet and dry years. Upon this assumption I base my contention that the <u>effective</u> drainage area of a spring can be calculated.

1 lines connecting points of equal rainfall

EVIDENCE AGAINST STREAM PIRACY BY SPRINGS

The U. S. Geological Survey, cooperating with the Missouri Geological Survey, made a series of discharge measurements on the Current River to determine if there was a direct connection between the river and the large springs. It was thought that possibly the springs were receiving water from the river, and later returning it to the river at the spring.

The following procedure was used:

A discharge measurement was made of the river several miles above the spring, one was made just above the spring, one made of the springs discharge, and one immediately below the spring. Any appreciable loss of water in the river above the spring could be detected by the first two measurements. Had a loss occurred between the first and second measurement and this loss had approximated the flow of the spring then intermediate sections would have been investigated to determine the location of the underground conduit, or water bearing stratum, that was robbing the river to supply the spring.

No evidence was found that the large springs along the Current River were receiving an appreciable amount of water from the river.

ORIFICE THEORY OF SPRING FLOW

In the case of the flowing spring the phenominum of the flowing water so quickly attracts attention, that the more important, but less obvious return to the surface of the diffused seepage of ground water, almost entirely escapes attention.[1]

A spring may be considered as the small orifice opening from a large storage tank. The orifice remains constant in area, in so far as this discussion is concerned. Since the capacity of the drainage area or underground storage tank remains constant, during the wet seasons the underground storage tank tends to become filled, thereby raising the hydraulic head above the orifice. A fundamental formula of hydraulics, is expressed as Quantity = Area multiplied by velocity, or, Q = A. V., now if the discharge is increased, the area of the orifice remaining the same, the velocity is greatly increased. This is shown by all the discharge measurements made on springs in Missouri.

The question might naturally be asked, that, since the opening in the rocks from which the spring issues is so "large", then why doesn't the orifice discharge all of the waters in the storage tank during long, extended dry periods? While it is true that the openings in the rocks are large when compared with a man standing beside them, still, in comparison with the volume of the

1 Sclichter, C.S., Motions of Underground Water U.S.G.S. w.s.p. 67 page 37

storage reservoir, these openings are relatively "small" openings, and therefore, during the dry months the discharge through the orifice does draw the water level in the storage tank down slowly. This is shown by the hydrographs of the springs of Missouri on which records of measurement have been made. As the hydraulic head of the water drops, the springs discharge less and less, and if the period of drouth is too long, the stored waters in the smaller drainage areas of the smaller springs is depleted to the level of the spring openings, and the spring discharges at less than full orifice. If the reservoir is not replenished, the spring finally ceases to flow at all. Greer Spring in Oregon County is the third largest spring in the Ozarks in point of average discharge.[1] It has two outlets; the upper one is 7[2] feet higher than the lower outlet, and, with just this relatively small difference in elevation, the upper outlet is often dry, or flowing only partially filled, and the cave through which it flows is said to contain many beauties.[3] At the time of the author's visit to this cave in December, 1937, the upper outlet was completely dry, and could have been entered and explored if suitable lights had been available.

Now each rain is like dumping many, many gallons of water into the hypothetical tank. The head on the orifice is increased

1 Bolon, "A Study of Missouri Springs" page 17
2 Meinzer, Large Springs in the United States Water Supply Paper U.S.G.S. 557 page 20
3 Owens, "The Limestone Caves of the Ozarks and South Dakota"

somewhat, increasing the discharge. The discharge continues at an increased rate until the water is drawn down below the point where the additional water was added. A typical hydrograph of a rise in Greer Spring after a local rain shows very clearly the typical orifice action in the springs of Missouri.

From the above example of the two outlet openings in Greer Springs, it appears likely that the "storage tank" basin of the spring is of large extent, but its surface is not relatively very high above the spring. It is more like a "lake" or chain of lakes than a "stand pipe", for in a stand pipe a small amount of discharge will produce a relatively large draw down. Fig. 2

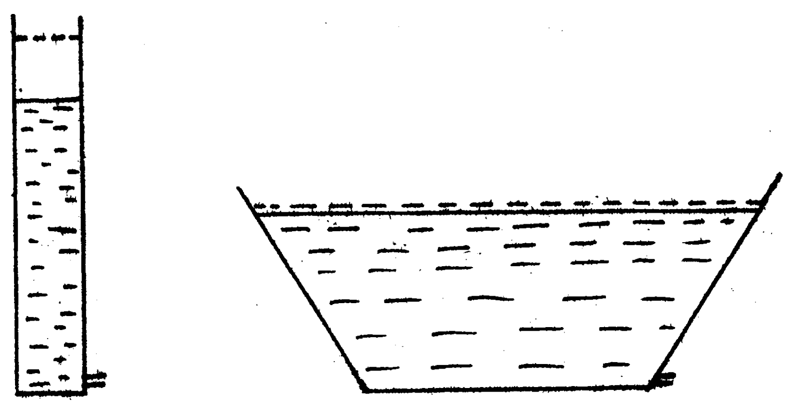


Fig. 2 Difference in draw-down between reservoir and stand pipe

It would be an interesting study to build a sand bag dam around any one of the larger springs (similar to the dams built behind levees around "sand boils") and thereby determine the static head necessary to cause the springs to cease to flow.

Table

G.H. (feet)	Discharge (cfs.
0.25	120.
.30	133.
.35	147.
.40	161.
.45	176.
.50	191.
.55	207.
.60	223.
.65	240.
.70	258.

Greer Spring at Greer Mo
(print of graph of Continuous
Water Stage Recorder)
U.S. Geological Survey

used with permission

Dec 7, 1937 – Jan. 2, 1938

Onandoga Spring was measured, by the author, on Dec. 30, 1937, and the flow was found to be 840,000 gallons per day. The staff gage is located in the farthest upstream explored portion of Missouri Caverns.

A small dam at the mouth of Onandoga Cave is used to form a lake in order that boats may be used to traverse the first quarter of a mile into the cave. The dam raises the water level so that the pool reaches to the foot of a small waterfall less than 100 feet from the gage. Missouri Caverns and Onandoga Caverns are all one natural cave with one natural and one drilled entrance.

This is one subterranean stream that can be measured before it emerges at the spring mouth. After very heavy rains the spring probably flows at full orifice, otherwise only partially full.

It is believed by the Author that the "storage tank" basin above Boiling Spring, Pulaski County, is located in the high plateau above the spring and that the elevation above the spring is such that if the proposed dam on the Gasconade River, below the spring, were constructed that the spring would merely build up a head equal to the one in the river and then start flowing as a submerged orifice, or from its abandoned solution channel, Onyx Cave, located higher on the hill.

It is my belief that the spring would continue discharging into the river at practically its present rate of flow. It has been thought that possibly under an increase of head at the mouth the spring might be reversed and not only the flow of the spring would be lost but also the spring's conduit might discharge water from the lake into another river basin.

A COMPARISON OF RUN-OFF BETWEEN EFFECTIVE DRAINAGE AREAS AND SURFACE DRAINAGE AREAS

The water supplying springs, and underground waters, percolates into the ground, flows into sinks, or joints, and flows through the pore spaces in the soil and rocks. The amount of such water is strictly dependent upon the rainfall, and the laws of hydraulics that govern its flow.[1] Under the action of gravity the surface of the ground water always tends to become a level surface, and as long as a supply is maintained through percolation, there will be a continual lateral flow, which will, on the average, be equal to the percolation.

The drainage area of Big Spring is about 440 sq. miles. There are 640 acres to the sq. mile. 440 X 640 = 282,000 acres surface exposed. During the calendar year 1935 the mean discharge was 454 cubic feet per second or only 2.4% below the mean discharge, of 465, for the entire period of record.

The quantity of water discharged during the calendar year 1935 was 328,410[2] acre feet.[3]

On the assumption that the drainage area was all of the same absorptive qualities, then each acre of the drainage area would have to absorb, and later give up to the spring the following depth

1 Turneaure, F.E., and Russel, H.L., "Public Water Supply" page 87
2 U.S.G.S. record "Big Spring Near Van Buren, Mo. 1936"
3 See definition of terms

of rainfall:

$\frac{\text{328,410 acre feet}}{\text{282,000 acres}} = 1.2$ feet, or 14.4 inches. This is not an unusually large amount, as most of the surface streams averaged very close to this figure.

Cuivre River near Troy	14.06	Calendar year 1935
Eleven Point River Bardley	18.43	Calendar year 1935
Black River at Leeper	19.11	Calendar year 1935
Big River at Byrnsville	20.77	Calendar year 1935
Gasconade River near Hazle-green	19.39	Calendar year 1935

The rainfall at Birchtree, Mo., 27 miles almost directly west of the spring, and lying just a few miles from the principal drainage area of Big Spring, has an average rainfall of 45 inches per year, according to the Weather Bureau, based on normal precipitation (based on all available records from 1898 to 1935) see rainfall map accompanying this report.

The intermittant streams, above springs, flow for a short time after heavy rains and this tends to rob the underground storage of the springs. One would be led to believe that the springs effective drainage areas would need to be increased in order to be comparable with surface streams in the area. However, it is believed that the subsurface percolating waters, supplying springs, flow deeper than the underground waters supplying the low water flow of surface stream, and therefore much less affected by the evaporation from the ground surface or by transpiration by growing vegetation.

Therefore, the author believes that these two conditions tend to nullify each other during normal years. In wet years the surface drainage will rob the subsurface drainage, during dry years the reverse will be true.

DETERMINATION OF THE EFFECTIVE DRAINAGE AREAS OF THE LARGE SPRINGS OF MISSOURI

It has been said that if you can express your problem in numbers or symbols, the problem is more than half solved.

At first the idea of measuring the effective drainage area of a spring may sound preposterous to you, for you would naturally say, "How can anyone measure the water seeping into the ground, and what area would you assign to the area furnishing waters to a spring, or how can one measure an area above ground for underground drainage?"

If an engineer is assigned the task of erecting an engineering structure of a hydraulic nature, he first investigates the stream. If there are stream flow records taken over a long period of years, the engineer will avail himself of them, and assume that what has happened over this period of years will be a pretty good indication of what to expect over a similar period in the future, (naturally, the floods or drouths will not occur in the same order, nor will he expect the river to have exactly the same discharge on the same day of the year five years hence that it had this year). (The calculation and operations of Bagnell Dam are a good example, with more than forty five years records on the Osage River.)

Next, consider the same engineer with the same stream; but this time we will say there are no available stream flow records on the stream in question. The engineer may establish a gaging station on the stream, and collect records for a short period of time, knowing full well that this time will give only an approximation of the nature of the stream, because the period of record may include only seasons of abnormal run-off. For example, 1927 or 1929, in which case his estimates would be far too high if extended over a large number of years. On the other hand, his period of record may include only a year or two of abnormally low run-off, such as 1936, in which case his estimate would be far too small if extended over a long period of time.

The engineer would probably establish a gaging station on the stream (if the time available permitted) and compare the records for that period with the records of a nearby stream of about the same drainage area, having similar shape of basin and topography, and receiving approximately the same rainfall, on which stream records had been kept over a long period of years. This latter method would give him a good idea as to what to expect from the stream in question.

As a last resort, the engineer with the problem would pick a coefficient from a handbook that was supposed to apply to <u>any</u> stream in, say, the Mississippi River Basin, and multiply the drainage area of the stream in question by the coefficient picked. This last method is about as accurate as most almanacs that predict the weather, day by day, for a year in advance. The last named method is used extensively for small areas for calculating the size of culverts, but after the size is determined, a large factor of safety is usually applied. It is apparent that the highway departments and railroad engineers do not use the same factors for the same size drainage area, as may be noted by the different sized culverts installed to take care of the drainage of the same drainage area at the same place. Often times one culvert will exceed the other by 100% or more, in area.

The author proposes to use the first and second methods mentioned. Namely, to use records collected over a long period of time, where possible, and compare these records with streams having similar characteristics (most often the springs will be compared with the river within whose basin it has its drainage area).

Stream discharge records have been kept on some of the larger springs in the Ozark region as follows: Greer Spring (1922-1937), Big Spring (1922-1937), Bennett Spring (1929-1937), Meramec Spring (1903-1906 and 1922-1929), Alley Spring (1929-1937), Hahatonka Spring (1923-1926), and Round Spring (1929-1937). Miscellaneous discharge measurements have been made at various times in the past at all the known springs having a flow of more than 10 cubic feet per second.

Bolon[1] determined the comparative size of the springs in

1 Bolon, H.C., Missouri School of Mines Unpublished Thesis, 1935

point of discharge by relating the discharge of each spring to the discharge of Greer Spring. His figures for the discharge of the various springs were used to compare the discharge of the springs with that of the surface streams in the vicinity of the drainage basin of the spring.

The next problem was to determine the location of the drainage area for each large spring. The areas were principally located by:

(1) Using published data by geologists;

(2) Studying maps of the region;

(3) Personal observations: and

(4) Studies relating to sinks, caves, mines and solution channels.

The direction of the main axis of the underground stream was determined, and the probable drainage area was indicated on the surface drainage map. Plate 5

Since the drainage basins of the springs lie within the various river basins of the region, the assumption was made that surface and subsurface run-off would be the same on adjacent small areas.

Points of equal run-off per square mile for the surface streams are shown in Plate 3

By combining the map of equal lines of run-off with the map showing the probable location and area of the effective drainage area supplying the individual springs, the run-off per square

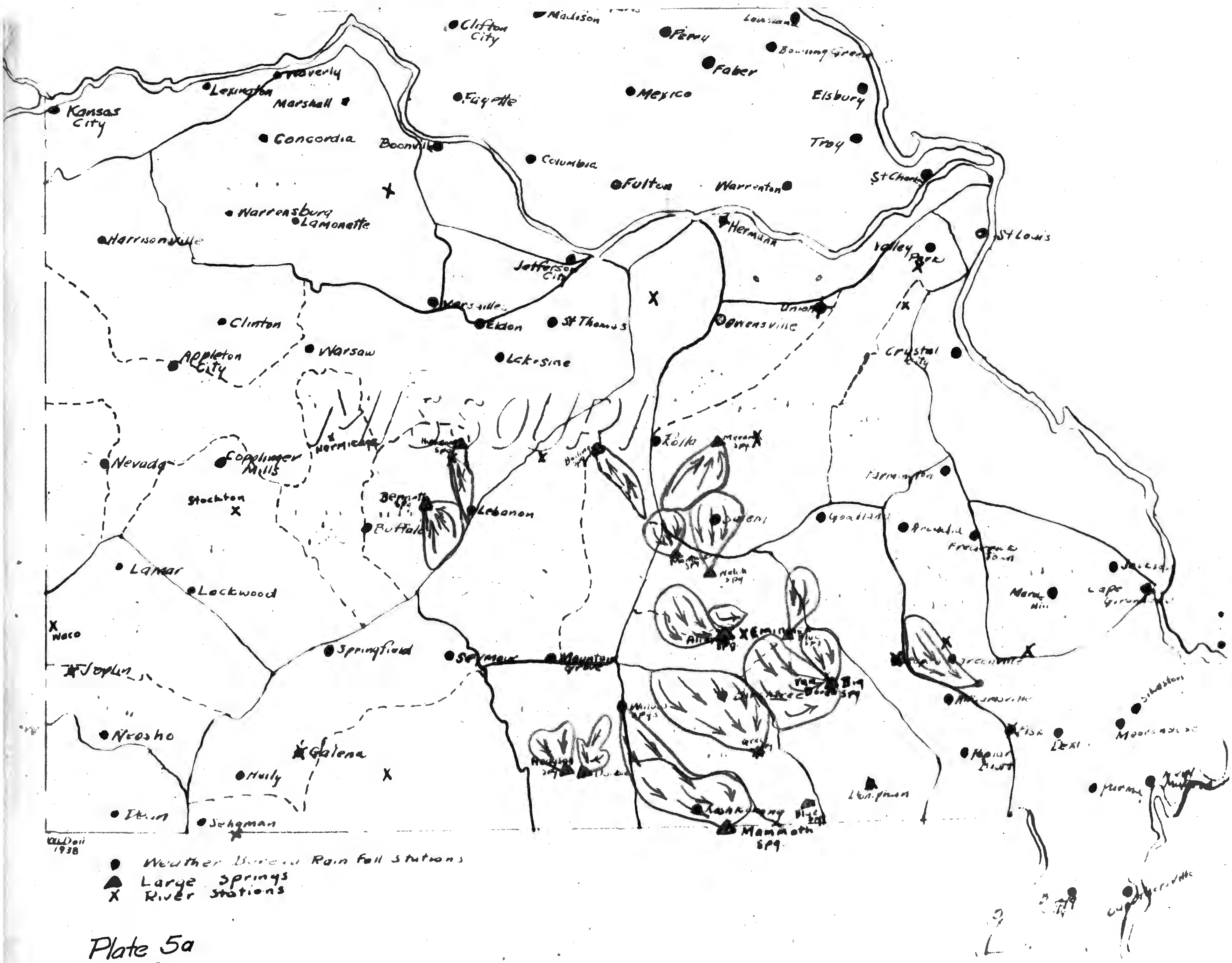


Plate 5a
Page 54a

mile of the springs drainage basin was determined. This factor is the "Missouri Spring Factor", and represents the quantity of run-off that may be expected from each square mile of the effective drainage area.

Using the Missouri Spring Factor determined for each individual spring and the comparative drainage for each spring, as determined by Bolon, the problem then resolves itself into the simple one, that of: If the discharge is a certain number of cubic feet per second and each square mile of the drainage area is assumed[1] to furnish an equal amount of water to make up this discharge, then discharge divided by the Missouri Spring Factor will give the number of effective square miles to supply the quantity to the springs. The author believes that over a period of about fifteen years the mean value of the discharges will give a close relation between surface and subterranean drainage areas.

Example; The drainage area of Mammoth Spring is located northeast of the spring and exerts a regional influence on the water table as far north as Willow Springs, Missouri. The shape of the basin is long and narrow, following the principal fault lines in the vicinity. The northern most portion of the basin lies within an area wherein the discharge is 1.05 c.f.s. per square mile --- the center portion, 1.10 c.f.s. per square mile, the southern portion of the drainage area lies in an area wherein

1 Bolon, H.C., previous citation

the discharge is 1.15 c.f.s. per square mile. An average of the whole drainage basin would be 1.10 c.f.s. per square mile (Missouri Spring Factor equals 1.10).

The comparative mean discharge for the spring is given as approximately 412 [1] cubic feet per second.

412 cubic feet per second divided by the Missouri Spring Factor of 1.10 = about 375 square miles in the effective drainage area for Mammoth Spring.

The effective drainage areas for other large springs were calculated in a similar manner, and the results are tabulated in table 5.

1 Bolon, H.C., previous citation

EFFECTIVE DRAINAGE AREAS OF THE LARGEST SPRINGS IN MO.

Rank (Bolon)	Spring	County	Comparative Run-off c.f.s.(Bolon)	Missouri Spring Factor	Effective Drainage Area
1	Big	Carter	465	1.05	440
2	Mammoth	Fulton, Ark.	412	1.10	380
3	Greer	Oregon	362	1.07	340
4	Double	Ozark	242	1.04	230
5	Welch	Shannon	180	.93	190
6	Bennett	Dallas	162	.92	180
7	Merâmec	Phelps	142	.88	160
8	Blue	Oregon	140	1.20	120
9	Blue	Shannon	139	.98	140
10	Alley	Shannon	127	.98	130
11	Blue	Wayne	122	1.18	100
12	Boiling	Pulaski	120	.90	130
13	Montauk	Dent	97	.93	100
14	Hahatonka	Camden	83	.90	90
15	Hodgson Mill	Ozark	78	1.03	80
16	Thomasson Mill	Oregon	57	1.20	50
17	Boiling	Texas	50	.95	50
18	Rockbridge	Ozark	50	1.03	50
19	Pultight	Shannon	48	.97	50
20	Stone Mill	Pulaski	45	.86	50

Table 5

EFFECTIVE DRAINAGE AREAS OF THE LARGEST SPRINGS IN MO.

Rank (Bolon)	Spring	County	Comparative Run-off c.f.s.(Bolon)	Missouri Spring Factor	Effective Drainage Area
21	Cave	Shannon	45	.97	50
22	Creasy	Pulaski	45	.85	50
23	Althea	Ozark	43	1.04	40
24	Keener	Butler	41	1.25	30
25	Coppedge	Phelps	40	.94	40
26	Prewett	Pulaski	38	.95	40
27	Round	Shannon	38	1.00	40

Note: The rank and comparative discharge of the large springs were determined by Bolon, in an unpublished thesis at Missouri School of Mines.

Table 5 (Continued)

INTERESTING FACTS ABOUT THE THREE LARGEST SPRINGS OF THE OZARK REGION

1. Big Spring
2. Mammoth Spring
3. Greer Spring

These three springs lie almost in a straight line with each other, forming a triangle with Greer Spring at the apex.

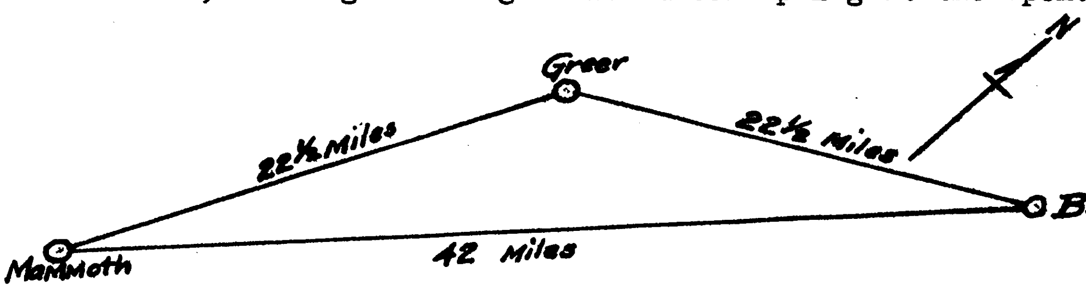


Fig. 3 Geographic relationship of Big, Mammoth, and Greer Springs

The elevations of the three springs compare as their rank in discharge. Big Spring having an elevation of 431 feet, Mammoth Spring 470 feet, and Greer Spring with an elevation of 545 feet above mean sea level. The larger discharge would be expected to be from the spring having the lowest elevation. However, Bennett Spring has an elevation of 866 feet, and ranks sixth in point of discharge. Showing that all large springs are not necessarily at a low elevation. The combined effective drainage area of the three springs is about 1160 square miles.

An inspection of the large drainage map will disclose the closeness of the indicated drainage areas. It appears reasonable that with the well developed underground drainage nets the three springs are probably interconnected in the upper portions of their drainage basins.

Some of the large springs are clear, while other large springs are muddy after severe storms. In the first case it is probable that the waters feeding the spring reached it by percolation through the porous earth or rocks, during which their impurities were largely removed. In the second, the waters probably entered at sinks or flowed into the rocks, as streams. In either case they are very liable to pollution due to matter washed in from the surface.

LIST OF SPRINGS WITH DESCRIPTIONS, PROBABLE LOCATION AND SIZE OF DRAINAGE AREA, SPRING FACTOR, AND STATEMENT OF MEASURED FLOW

Alley Spring

Alley Spring is located in sec. 25, T. 29 N., R. 5 W., at Alley, 5 miles west of Eminence, Shannon County. It issues from the base of a rocky cliff, flows over a dam which develops power for a grist mill, and empties into Jacks Fork at a distance of a half-mile. The dam forms a small lake of clear, blue water. The spring is the principal feature of Alley Spring State Park.

"The sources of the water for the spring are believed to be in the plateau region to the north and west of the spring. An interesting story, which appears to be well authenticated is told about this spring: On a certain day the flow of the spring was observed to be decreasing rapidly and it finally ceased altogether and the water in the spring basin sank to about five feet below its normal level. It remained in this condition for about twelve hours and then suddenly resumed flow. For several days the water was quite muddy but it gradually cleared up. At about the same time a large sink was suddenly formed in the plateau about 15 miles to the northwest of the spring. It appears quite probable that the material which fell into the underground channel when this sink was formed, blocked the channel temporarily and thus checked the flow of the spring". [1]

Records of the daily flow of the spring have been collected from October 1928 to date. These records include the occasional run-off from the small creek above the spring outlet. During the period of record the flow was as follows:

	Date	Second-feet	Gallons
Maximum	Mar. 1935	1060	704,000,000
Minimum	Dec. 1931, Apr. 1932	56	36,200,000
Average		117	75,600,000

The average monthly and yearly flow in second-feet for hydraulic years ending September 30 is given in the following table:

1 Bridge, Josiah, Geol. of Emin. & Cardareva Quads. Mo. G.S. Sec. Series Vol. 24 page 41

Hydraulic Data for Alley Spring

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Avg.
1929	-	107	151	181	167	193	256	337	262	181	155	119	
1930	112	125	116	189	202	167	105	111	95	83	77	109	124
1931	120	84	112	78	182	209	174	142	110	85	96	80	121
1932	61	62	65	181	97	92	94	66	71	76	66	60	81
1933	70	79	120	167	86	103	238	322	156	99	83	87	135
1934	78	77	76	79	68	76	88	62	66	61	61	71	72
1935	58	63	80	111	72	254	142	128	321	202	122	84	137
1936	80	134	107	84	87	82	77	62	65	63	63	80	82
Avg.	83	91	103	134	120	147	147	154	143	106	90	86	117

Table 6

Bennett Spring

Bennett Spring (also called Niangua or Brice Spring) is located in sec. 1, T. 34 N., R. 18 W., Dallas County, half a mile southeast of Brice. It issues from a circular basin about 50 feet in diameter in the bed of Spring Creek, and flows $1\frac{1}{2}$ miles into Niangua River. A dam about half a mile below the spring outlet is used to divert water through the state's fish hatchery and also to a grist mill. The beautiful surroundings, the spring, dam, fish hatchery and abundance of rainbow trout are the principal features of the Niangua State Park.

Comparisons between the rainfall at Lebanon, Mo. and the automatic water stage chart shows that for the extremely dry period of the summer of 1936, the spring apparently lags behind the rainfall at Lebanon by about one day.

The spring probably gets most of its water from the dry basin of Spring Creek and also more than likely drains the upper portions of Cave, Four Mile, Dousinburg and Jones Creeks.

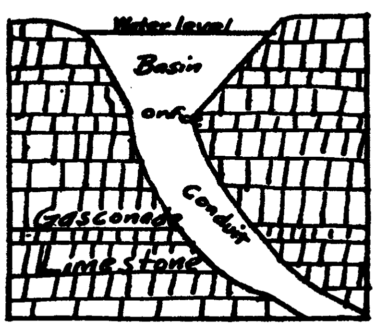


Fig. 4. Meinzer's diagram of Bennett Spring

The spring often flows muddy at high stages showing that it has direct connections with surface water---probably through sinks in the vicinity.

After heavy rains, the spring receives some surface water inflow from Spring Creek. Spring Creek bed is dry except after heavy rains, and is floored with gravel.

The major axis of the spring's drainage basin lies to the south of the spring and the Missouri Spring Factor is .92.

The drainage area is about 180 square miles.

Bennett Spring is at an elevation of 866 feet above mean sea level and is the highest of the large springs in the Ozark Region.

The daily flow of the spring from Sept. 9, 1916, to March 31, 1920, was determined by the Engineering Experiment Station, University of Missouri. Daily records have also been obtained from October 1928 to date. These records also include the very occassional run-off from the, ordinarily, dry bed of Spring Creek above the spring. Since October 1928 the record of the flow has been as follows:

	Date	Second-feet	Gallons per day
Maximum	June 1935	Not determined- - - - - - - -	
Minimum	Nov. 1934	55	35,500,000
Average		147	95,000,000

The average monthly and yearly flow in second-feet for hydraulic years ending Sept. 30 is given in the following table:

Hydraulic Data for Bennett Spring

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Avg.
1929	140	152	149	163	142	204	315	488	214	165	176	139	204
1930	152	142	130	215	218	179	147	127	119	109	100	120	146
1931	97	91	100	89	129	149	141	184	127	115	153	160	128
1932	101	122	135	193	138	131	129	121	182	142	103	94	132
1933	82	82	162	158	131	161	233	410	178	126	113	125	164
1934	143	99	89	90	81	120	126	92	88	80	94	122	102
1935	87	78	111	99	108	348	159	240	704	262	142	124	205
1936	131	106	87	88	85	85	85	103	85	93	78	92	93
Avg.	117	109	120	137	129	172	167	221	212	136	120	122	147

Table 7

Big Spring

Big Spring is located in sec. 6, T. 26 N., R. 1 E., 4 miles southeast of Van Buren, Carter County. It issues from the base of a rocky cliff and hill and flows into Current River at a distance of 800 feet. The water is clear and cold. On the lower side of the spring branch is a high, rugged, and wooded hill, and on the upper side a pretty valley. The large volume of clear, sparkling water gushing out from the base of the rocky cliff and the picturesque surroundings make this a very beautiful place. The spring is the principal feature of the Big Spring State Park. It can be reached readily by driving from Van Buren and is visited by many tourists. A suitable camping site and some other accommodations are provided.

As the spring issues at only a slight elevation above Current River it is not directly adapted to the development of water power. However, on account of the large amount of water which it discharges into Current River its study is important in connection with prospective power developments on the river.

This is the largest spring in the State. So far as can be learned it is the second largest individual spring in the United States, and is exceeded only by Silver Spring in Florida.

The major axis of the spring's drainage basin lies to the west and the northwest of the spring while some of the water probably comes from south of the spring and still other waters are thought to come from the east.

Davis Creek, and its tributaries, Pike Creek and Sycamore Creek, are dry stream beds most of the year, except after heavy rains. The valleys are as wide or in some cases wider than the valleys of the Current River or Jacks Fork River. Like them they are floored with alluvial depostis. After heavy rains these intermittant streams may become raging torrents for a few hours and may do a great amount of damage, but the flood soon subsides and within a few days at the most, the stream beds are dry again. Such conditions point to a well developed system of underground drainage.

There are a number of sinks in the bed of Davis Creek just south of the town of Midco and it is definitely known that water draining into these comes to the surface again in Big Spring which is 10 miles away in a straight line. When a plant at Midco was in operation, during the war, quantities of chemical waste were discharged into the dry bed of Davis Creek at Midco, and this soon contaminated the water of Big Spring.[1]

In the NE$\frac{1}{4}$ sec. 18 T. 27 N., R. 2 W., there is a sink hole about 70 feet in diameter in the floor of the valley. During wet seasons the water rises to within a few feet of the rim, but in dry seasons the hole is about 20 feet deep and connects with

1 Bridge, Josiah, Mo. G.S. Series 2 Vol. 24 page 36-40

an underground passage in which a stream flows to the southeast. This passage has not been explored, but the inhabitants of the vicinity claim that the light of a candle place on a small board and set afloat on the stream may be seen for a long distance. This stream is probably one of the feeders of Big Spring.[1]

A sink formed suddenly, a few yards west of the railroad station at Low Wassie, Mo., about the year 1927. Big Spring ran muddy 16 to 18 (est.) hours after the sink occurred. Showing direct evidence that the spring receives water from as far away as Low Wassie, a straight line distance of 14½ miles from the spring. A small stream emptied into the sink. The railroad dumped many carloads of rock into the sink to catch the surface wash so as to make the sink impervious in order to protect the railroad right-of-way from further solution sinks.[2]

Recently when a well was being drilled on the farm of C.P. Turley near Midco, after the drill had penetrated the rock for a certain distance it dropped through the roof on an underground cavern. One can hear running water in the cavern by listening at the well opening. Permission has been granted to put a dye into the well to determine the outlet for the water.[2]

There is a cave on State property several miles to the south of the spring, and a State employee told Davis that the

1 Bridge, Josiah, previous citation
2 Davis, Ben A., U.S.G.S. gage reader at Van Buren, Mo., personal statement.

roar of running water could be heard plainly.[2]

Bridge[1] points out that the area that drains underground to Big Spring must be very large and doubtless contains most of the drainage basin of Pike, Sycamore, and Davis Creeks and the upper portion of Mill Creek as well as a large territory south and east of the Eminence region and says that it probably receives some of its water from some of the dry valleys on the north side of Current River.

The spring is only about 6 feet above the mean level of the Current River and it is thought highly possible that a porous stratum may carry the water under the river.

The Missouri Spring Factor is 1.05 and the drainage basin is about 440 square miles in area.

This is a regular discharge station and records have been collected since April 1923.

On March 3, 1938, the gage height was 2.11 with a discharge of 511 c.f.s. or 330,000,000 gallons per day.

Frequent rains had raised the water table to a height so that an outlet, about 5 feet above and 150 feet downstream from the main opening was flowing.

1 Bridge, Josiah, previous citation
2 Davis, Ben A., U.S.G.S. gage reader at Van Buren, Mo., personal statement.

The main spring opening had a standing wave about $2\frac{1}{2}$ feet high over the mouth of the conduit. The water was slightly turbid.

Records of the daily flow of the spring have been collected from January to June 1922 and April 1923 to date. During these years the flow has been as follows:

	Date	Second-feet	Gallons per Day
Maximum	June 1928	1,300	840,000,000
Minimum	July 1936	247	164,000,000

The average monthly and yearly flow in second-feet for hydraulic years ending September 30 is given in the following table:

HYDRAULIC DATA FOR BIG SPRING

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Avg.
1922	-	-	-	358	414	469	460	490	413	-	-	-	-
1923	-	-	-	-	-	-	493	499	413	416	364	347	-
1924	342	330	355	338	349	351	351	371	401	381	346	329	354
1925	300	294	300	296	335	339	338	361	342	304	282	293	315
1926	412	461	477	352	445	533	520	385	358	320	298	278	403
1927	304	442	361	364	558	407	a	a	a	628	a	525	-
1928	476	527	a	568	559	a	a	546	a	a	563	494	-
1929	434	408	495	422	a	598	a	a	583	480	489	413	-
1930	398	439	521	724	661	565	424	426	377	351	335	338	462
1931	344	322	340	309	426	487	486	423	345	328	352	345	375
1932	327	325	339	518	427	423	366	317	297	288	288	276	349
1933	271	294	363	563	405	437	678	694	502	394	355	535	441
1934	330	327	325	317	303	349	317	300	276	292	272	312	315
1935	269	273	290	355	306	655	511	507	707	582	431	353	437
1936	331	364	330	303	298	279	279	261	253	249	252	272	289

a Spring affected by backwater from Current River.

Table 8

Blue Spring

Blue Spring is located in $NE\frac{1}{4}$ sec. 21, T. 29 N., R. 2 W., 12 miles east of Eminence, Shannon County. The water, which has a deep blue tint, flows with scarcely a ripple from a deep basin at the foot of a rocky cliff, then goes swiftly down the spring branch one-fourth mile, and empties into Current River. The spring with its rugged and wooded surroundings is one of the most beautiful places in the state. It can be reached best by driving from Ellington, although the road for a part of the way is very hilly and rough.

"Blue Spring appears to derive most of its water from th Logan Creek drainage basin, though the upper portion of Car Creek may also be a contributer. Logan Creek which is dry except for short stretches most of the year contains a number of sinks into which small streams are continually running, and a number of others which carry the surface water away rapidly in time of high water. It has been observed that Blue Spring always rises after heavy rains on the upper portion of Logan Creek, but that it is not affected by rains on the upper portion of Current River.

In addition to the evidence already presented, the following observations seem to confirm this belief:

1. The general trend of the porphyry ridges is northwest-southeast and the eastern boundary of the central porphyry mass is a few miles west of Blue Spring.—— As this rock is practically impervious not much ground water may be expected to migrate toward

Blue Spring from the west or south.

2. The general dip of the stratified rocks is from Logan Creek towards Blue Spring, and the latter lies almost in the trough of a sharply asymmetrical syncline, and therefore the water might easily migrate down the dipping bedding planes; and be forced to the surface when it reached the bottom of the trough.

3. The valley of Logan Creek is about 200 feet higher than the spring.[1]"

The above facts seem to show very clearly that the waters from the Black River Basin are probably being pirated by the Current River Basin, which fact may be noted on map __2__. The lines of equal run-off, dip sharply towards the Black River Basin, although the rainfall map __1__ shows that the rainfall on the two drainage basins is practically the same. In computing the chart __3R__ showing the corrected lines of equal run-off the drainage area for the upper portion of the Black River Basin was decreased by 60 square miles and the lines then more nearly followed the lines of equal rainfall, but still showed a rather decided dip indicating that the area subtracted might still be too small. From computations the effective drainage area of Blue Spring was found to be 142 square miles, of which a little more than half seems to be in the Black River Basin, the rest in the Current River Basin.

1 Bridge, Josiah, Geology of the Eminence and Cardareva Quadrangles Vol. 24 second series pages 40-41

The major axis of the springs drainage basin lies to the north and northeast of the spring and the Missouri Spring Factor for the basin is .98 c.f.s. per square mile.

The average comparative run-off of the spring is given as 139[1] c.f.s.

This would give an effective drainage area of 142 square miles.

The drainage area indicated on the large drainage map of Missouri was run twice with a planimeter and the area averages 148 sq. miles. The area in the Black River Basin averages 100 square miles.

Measurements of the flow have been made as follows:[2]

Date	Second-feet	Gallons per day
Aug. 1, 1923	133	86,000,000
Oct. 11, 1923	84	54,300,000
June 25, 1929	214	138,000,000
Oct. 10, 1932	62	40,100,000
Aug. 6, 1936	68	44,000,000

1 Bolon, H. C., previous citation
2 Records of the U. S. Geological Survey, Rolla, Missouri

Blue Spring

Blue Spring is located in sec. 16, T. 22 N., R. 2 W., 18 miles southeast of Alton, Oregon County. It issues from the base of a rocky cliff about 150 feet high, called "The Narrows," which separates Fredericks Fork from Eleven Point River, and flows into the latter stream at a distance of 1000 feet. It is a picturesque place.

Measurements of the flow have been made as follows:

Date	Second-feet	Gallons per day
Aug. 12, 1925	67	43,300,000
Oct. 25, 1932	64	41,400,000
Sept. 14, 1933	70	45,200,000
Aug. 17, 1934	59	38,100,000
July 18, 1935	100	64,600,000
Aug. 13, 1936	54	34,400,000

The Missouri Spring Factor for the spring is 1.20 and the effective drainage area is about 120 square miles.

Blue Spring

Blue Spring (also called Davidson Spring) is located in sec. 4, T. 27 N., R. 6 E., 2 miles southwest of Kime post office, Wayne County, and 6 miles south of Greenville. It issues from the base of a rock ledge and flows about three hundred feet into St. Francis River. The spring and the abundance of pine trees surrounding it makes it a popular place. Tourist cabins are located nearby.

The Missouri Spring Factor for the spring's drainage area is 1.18.

The drainage area is about 100 square miles in area.

Measurements of the flow have been made as follows:

Date	Second-feet	Gallons per day
Oct. 30, 1932	48.6	31,400,000
Aug. 15, 1934	46.0	29,700,000
Aug. 10, 1936	42.3	27,400,000

Boiling Spring

Boiling Spring is located in sec. 33, T. 37 N., R. 10 W., 4 miles northeast of Hooker, Pulaski County. It bubbles up in the bed of Gasconade River just below the mouth of Piney Creek. When the river is high the spring is submerged.

The spring was visited in 1933.

The spring is utilized for drinking purposes by the familys living on top of the almost vertical bluff over-looking the spring --- by the use of a bucket on a long wire stretched down to the spring.

At the time of the visit the Gasconade was at a rather low stage and the spring was about half in the river bed and half out of the river, and appeared to bubble up in a circular basin.

The major axis of the drainage basin appears to lie to the south east of the spring.

There are at least 26 large sinks, 11 caves large enough to be named and practically no surface drainage indicated as shown from an inspection of the Phelps County tourist map drawn to a scale of 1-inch equals 2 miles. The above statements attest the fact that the underground drainage is very highly developed.

A question that has been asked, in connection with a proposed dam installation on the Gasconade River, is whether the spring would continue to discharge if submerged under a head of water to a depth say of 50 feet and also whether the head would be sufficient to force water back up through the solution channels of the present spring to a height sufficient to cause the waters to flow off into another river basin (similar to a tunnel by-pass).

It is believed that the spring would be able to build up enough head to overcome the external head and would continue to discharge at approximately the same discharge that it has at the present time. Very likely the spring would change its outlet to one of the abandoned outlets at a higher level. The spring in ages past discharged at a higher level, but as the bed of the

Gasconade was eroded the spring sought outlets at lower levels until today it has an outlet at the water level of the river. As the river bed is eroded still farther then the spring will come from a cave in the bluff, as the river level will have dropped away.

If a power dam is put in, the stored waters will react upon the spring just as the great storage of underground waters do.

The abandoned solution channels and caves will give added underground storage capacity to the reservoir.

The author believes that there is no likelihood of the water being forced back into the spring's channels far enough to cause the spring to reverse and act as a conduit for the water to flow out of the Gasconade basin.

As the surveys and borings have been made on the proposed power site it would cost a relatively small sum to check this theory, by building a sand bag dam around the spring to the height that the water would be raised by the proposed dam.

Many large springs have been sounded to a depth in their own pool greater than the proposed submergence planned for this spring.

The above theory is in line with the orifice theory for if the lower orifice were plugged then the reservoir would store water until the next higher orifice had been reached and would then discharge through this higher orifice.

This spring, and other springs like it, are of an unusual character in that they boil up in the river bed, a person unfamiliar with the method used might wonder how the quantity flowing from the spring can be measured. It is possible to measure in several ways the water flowing in a spring branch. The most practical one, and the one used by the U. S. Geological Survey, is to measure the quantity of water in the river above the spring, and measure the quantity of water in the river below the spring. Then the difference in the two measurements will give the quantity of water added by the spring.

The flow on Sept. 21, 1923 and Oct. 21, 1932 was 65 cubic feet per second or 42,000,000 gallons per day.

Coppedge Spring

Coppedge Spring (also called Relfe Spring and Freeman Spring) is located in sec. 36, T. 35 N., R. 10 W., at Relfe, Phelps County. The spring issues from the side of road and flows into Spring Creek a short distance away.

This spring was visited early in 1938 and at the time it was noted that the spring branch from this spring was furnishing all of the flow of Spring Creek. Above the spring, the broad valley of Spring Creek was entirely dry. The floor of the stream bed is composed of rather large size gravel. An inspection of various maps shows several sinks, large enough to be shown on the maps, in the floor of the valley of Spring Creek.

The major axis of the spring's drainage basin lies to the south and east of the spring. The Missouri Spring Factor for the basin is .94 c.f.s. per square mile and the comparative discharge is given as 40 c.f.s.

The calculated effective drainage area is 43 ± square miles.

Measurements of the flow have been made as follows:

Date	Second-feet	Gallons per day.
Nov. 24, 1923	23	15,000,000
May 26, 1925	29	18,000,000
Sept. 12, 1925	20	13,000,000
Oct. 20, 1932	16.6	10,700,000
Aug. 2, 1934	15.4	9,950,000

Double Spring

Double Spring is located in NE¼ NE¼ sec. 32, T. 24 N., R. 11 W., 4 miles northeast of Dormis, Ozark County. It issues from the base of a bluff. The water flow divides 50 feet from the outlet, one branch flowing north 700 feet into North Fork of White River and the other south 1,500 feet into the same stream. It is rather inaccessible on account of rough roads, but is visited by quite a number of people. Measurements of the flow have been made as follows:

Date	Second-feet	Gallons per day
Aug. 8, 1919	136	[a] 88,000,000
Sept. 6, 1924	163	105,000,000
Sept. 7, 1925	82	53,000,000
Aug. 18, 1934	142	91,800,000
Aug. 17, 1936	58.6	37,900,000

The major axis of the spring's drainage area is thought to lie to the north of the spring and the Missouri Spring Factor is 1.04. The effective drainage area is about 230 square miles.

Greer Spring

Greer Spring is located in Sec. 36, T. 25 N., R. 4 W., 1 mile north of the village of Greer, Oregon County. It has two outlets 300 feet apart and at a difference of elevation of about 7 feet, both of which are located in a deep, narrow gorge. At the upper outlet the water flows horizontally from a cave in the rocks. At the lower outlet it boils up in a circular basin. The water is clear and cold, the temperature averaging about 58° throughout the year. The water rushes through a branch one and one quarter miles long throughout which it falls 46 ft. and then empties into Eleven Point River. The large volume of clear water

[a] Measured by Engineering Experiment Station, University of Missouri

rushing through the narrow, rocky, valley with its heavily wooded slopes makes this a place of extraordinary beauty and grandeur. It is one of the scenic gems of the State. The place is privately owned, but visitors are permitted. It can be reached readily by driving from Alton, Mo.

The large and uniform flow of the spring combined with the rather large fall in the spring branch and short length of dam necessary to span the channel, make this a good location for a moderate sized water power development. The spring being considerably higher than the normal high water elevations of the Eleven Point River, it is not affected by back water, or damming of the spring due to water being backed up the spring branch and acting as a water dam, and is therefore used as the key spring in determining the discharge of large springs that are submerged or affected by backwater from the rivers into which they empty.

The close relation between four of the large springs to each other, and also to the Current River is shown in the 1937 hydrographs plotted on three cycle logarithmic paper. Chart 6 was used in the determination of the discharges of the springs during periods when they were affected by backwater from the rivers into which they empty. The chart is a print from the unpublished records of the U. S. Geological Survey.

The fluctuations of Greer Spring are closely related to the precipitation at Birch Tree, Mo., 18 miles distant, as record-

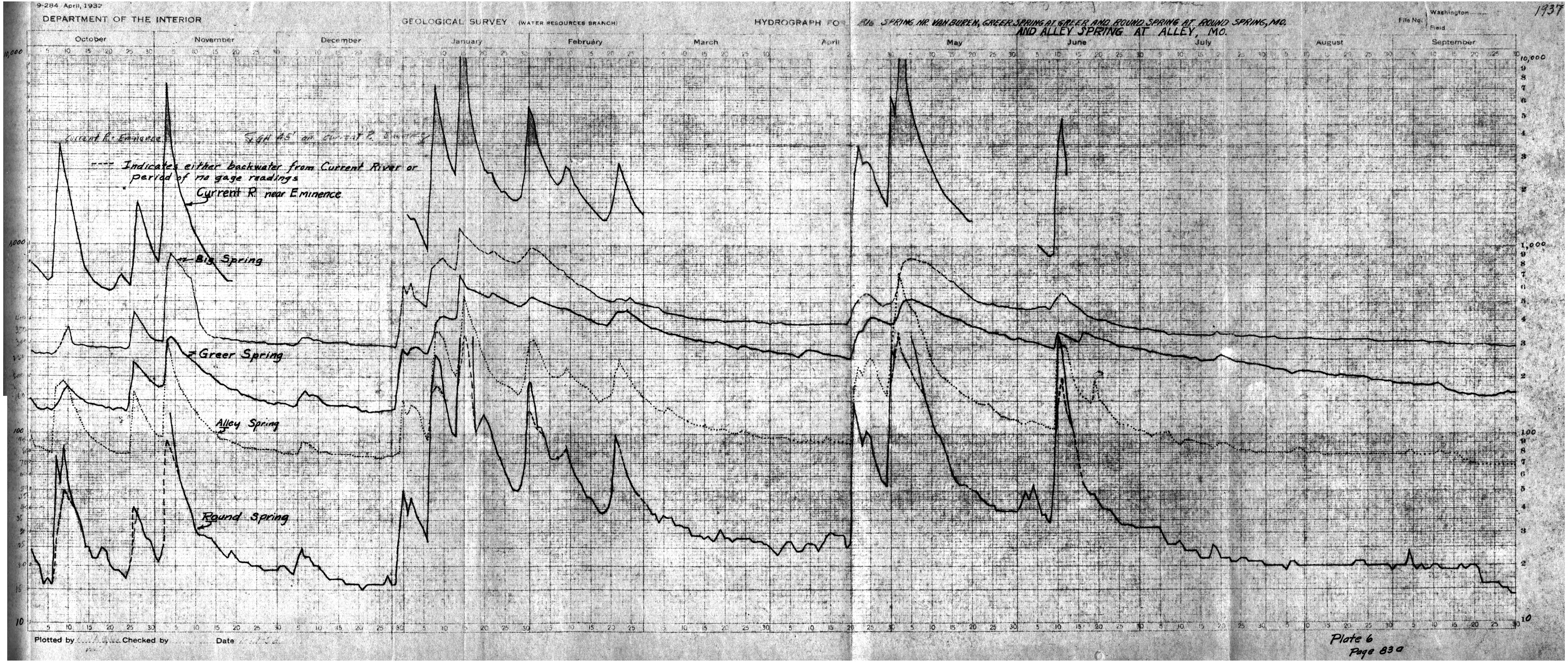


Plate 6
Page 83a

ed by the U. S. weather bureau.

The effective drainage area of the spring is about 340 sq. miles and the major axis lies to the north and northwest of the spring. The basin is thought, by the author, to cover most of the northern portion of the drainage area assigned to the Eleven Point River.

The evidence for the above assumption is listed below:

1. The topography along U. S. Highway 60 between Willow Springs, Mountain View, Montier, Birch Tree, and Winona, Missouri, is that of broad, shallow valleys with practically no surface drainage, even during periods of moderately heavy rainfall.

2. Numerous large, and medium sized sinks attest the highly developed underground drainage of the region. Some of these sinks may be seen from U. S. Highway 60 between Willow Springs and Birch Tree. Small streams empty into some of these sinks in times of wet weather.

3. At least two sinks have formed suddenly within the last twenty years, showing that the underground solution is still quite vigorous in this neighborhood.

a. A large sink was formed by the sudden collapse of the roof of a subterranean passage. The sink formed some time between 1929 and 1932. The location is given as being in the "Chapel Hill Neighborhood" located approximately 5 miles south of Mountain View, Mo. Local inhabitnts reported that whole trees dropped into the sink.[1]

b. A somewhat smaller sink than the one described in a. formed suddenly 15 or 20 years ago on the "Whitt Holden farm" approximately 4½ miles south and 1 mile west of the town of Montier, Mo. This sink was estimated as being, roughly, 50 feet in diameter.[1]

Mr. Davis[1] states that probably many other sinks have occurred that have been unreported because the local inhabitants apparently do no know to whom to report the occurrence, or else are under the belief that the occurrence of a sink is of no interest to outsiders. Information of this nature sent to the U. S. Geological Survey or the Mo. Geological Survey, located in Rolla, Mo., might help to establish more closely the boundaries of the drainage areas of the large springs.

Records of the daily flow have been collected from

1 Davis, Ben A., Water gage observer for the U. S. Geological Survey, living at the Rose Cliff Hotel in Van Buren, Mo. He is greatly interested in the hydrology of the large springs and rivers in the southern part of the Ozark Region. He is also a student of legends of the Osage Indians that hunted in this region prior to, and during, the settlement by the pioneers.

December, 1921, to date. During this period the flow has been as follows:

	Date	Second-feet	Gallons per day
Maximum	1927	903	584,000,000
Minimum	Aug., Sept., 1936	116	75,000,000
Average	1921-1936	347	224,000,000

The average monthly and yearly flow in second-feet for hydraulic years ending Sept. 30 is given in the following table:

Hydraulic Data for Greer Springs

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Avg.
1922	-	-	355	284	274	454	681	534	410	390	314	286	
1923	273	270	236	352	521	500	444	466	507	356	333	300	380
1924	264	239	291	250	244	224	226	316	441	387	328	253	289
1925	210	203	206	221	260	262	264	306	234	173	160	216	226
1926	414	522	394	308	333	375	372	310	278	248	213	227	333
1927	246	377	324	427	433	435	724	776	861	572	563	458	516
1928	442	531	750	648	496	454	707	525	652	539	542	503	566
1929	432	411	398	379	424	452	615	771	673	431	410	341	478
1930	331	360	344	522	492	519	402	476	399	281	269	255	387
1931	285	231	237	224	367	481	450	436	350	299	302	258	327
1932	240	229	246	387	352	318	274	223	199	190	174	157	249
1933	146	154	190	422	323	329	594	677	556	379	316	271	363
1934	231	210	212	217	196	234	301	220	181	149	143	201	208
1935	142	132	156	232	219	423	387	387	588	506	409	307	323
1936	257	259	261	202	187	169	180	143	140	127	122	134	182
Avg.	279	295	307	338	341	375	441	438	431	335	307	278	347

Table 9

Hahatonka Spring

Hahatonka Spring is located in sec. 2, T. 37 N., R. 17 W., at Hahatonka, Camdem County. It emerges from the base of a rocky bluff, flows through a narrow, precipitous canyon about 1,000 feet long, and enters directly into the Lake of the Ozarks.

The clear, sparkling water in the spring branch and lake, the surrounding rugged country, and the deep wooded valley make this one of the most picturesque and imposing landscapes in the State. The place is widely known for its scenic beauty and is visited by many tourists. The owner of the property maintains cottages, a dining hall, camp grounds, boats, and other conveniences, which are rented to visitors. The place can be reached readily by driving from Lebanon. The spring is flooded when the Niangua River is high.

The major axis of the spring's drainage basin is thought to be south of the spring and probably collects water from as far away as Lebanon, Mo.

The Missouri Spring Factor is .90 and the effective drainage area is about 90 square miles.

Records of the daily flow have been collected from November 1922 to June 1923 and from October 1923 to Sept. 1926. The average monthly flow in second-feet during the periods for Hydraulic years ending Sept. 30 is given in the following table:

Hydraulic data for Hahatonka Spring

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Avg
1923	-	60.9	57.2	50.3	46.9	59.1	54.6	49.5	75.7	-	-	-	-
1924	52.8	64.0	a	61.0	77.9	64.8	a	a	a	a	a	88.7	-
1925	64.3	65.8	a	a	87.8	a	a	85.8	70.4	63.7	64.0	a	-
1926	90.8	94.6	76.2	63.7	64.5	80.2	95.3	68.0	62.0	56.0	65.5	84.8	75.1

[a] Spring affected by backwater from Niangua River

Hodgson Mill Spring

Hodgson Mill Spring is located in sec.34, T. 24 N., R. 12 W., near Sycamore, Ozark County. It issues from a rock ledge over which stands a grist mill that utilizes the direct fall of 9 feet. It flows into Bryant Creek at a distance of 600 feet.

The Missouri Spring Factor for the the spring's drainage basin is 1.03.

The major axis of the spring's drainage basin is thought to be north and northwest of the spring and its area is about 80 square miles. Measurements of the flow of the spring have been made as follows:

Date	Second-feet	Gallons per day
Aug. 29, 1926	24	15,500,000
Oct. 17, 1932	34.4	22,200,000
Aug. 18, 1934	44.7	28,900,000
Aug. 18, 1936	28.1	18,200,000

Mammoth Spring

Mammoth Spring is located near line between secs. 5 and 8, T. 21 N., R. 5 W., at the town of Mammoth Spring, Fulton County, Arkansas, just south of the Missouri State line. By means of a dam in the spring branch, hydro-electric power is developed to serve several towns in that vicinity. A Government fish hatchery is

Generalized Diagram
Showing
Static Water level and Geological Formations
in
Wells and Springs from
Willow Springs to Mammoth Spring
Copied from H.S. Mc Queen's diagram
of June, 1930

W.L. Doll
1938

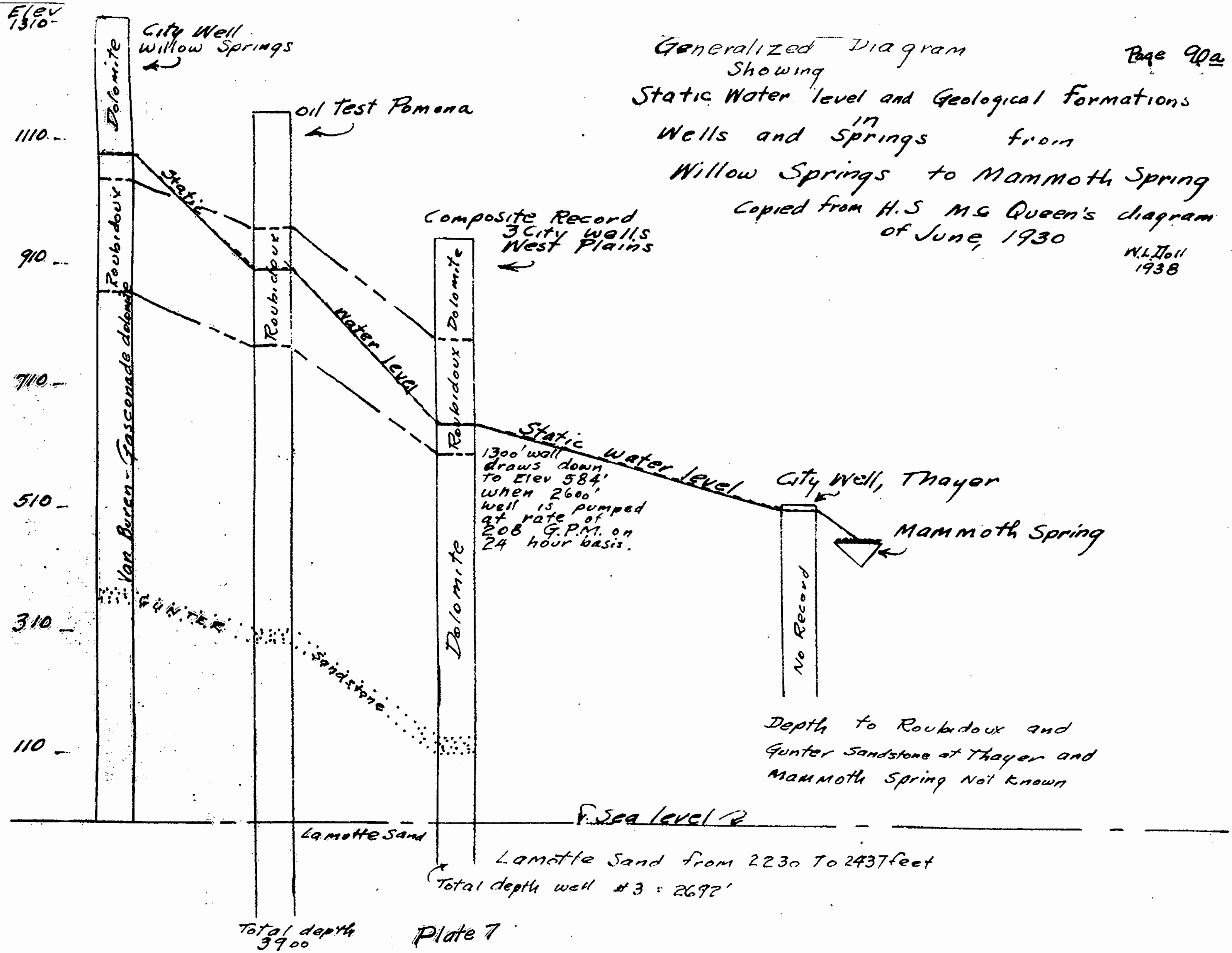


Plate 7

located at the spring. On December 11, 1924, the flow was 240 second-feet or 155,000,000 gallons per day, and on June 11, 1926, it was 310 second-feet, or 200,000,000 gallons per day.

As there is considerable local difference of opinion in regard to the flow of this spring as compared with that of Big Spring near Van Buren, Mo., and Greer Spring at Greer, Mo., the following table is given to show the comparative flow of the three springs in terms of gallons per day on the dates on which the measurements described above were made:

Date	Big Spring	Mammoth Spring	Greer Spring
Dec. 11, 1924	183,000,000	155,000,000	133,000,000
June 11, 1926	231,000,000	200,000,000	180,000,000

Many geologists have made mention of the fact that the course of the subterranean stream feeding Mammoth Spring may be traced from a large sink hole known as "Grand Gulf" eight miles northwest of the spring. Grand Gulf is approximately three quarters of a mile long and was the result of the underground stream undermining the roof, causing it to fall into the channel.

McQueen[1] made field studies in the vicinity to determine the location for drilling a well for the water supply of West Plains, Mo. The well was later drilled upon his recommended location and an ample supply was obtained. With his permission I

1 McQueen, H. S., unpublished letter

am quoting from his unpublished letter, his theories as to the underground drainage above Mammoth Spring. "From recent field work I came to the conclusion that there was a fracture or fault zone trending in a general northwest-southeast direction, which passes through the Morrison and Carson mines and thence through the east part of West Plains. The dolomites and magnesian limestone along this fracture zone have been dissolved, the work of the solution being expressed by the many sink holes which are located in the area of the zone, as well as the occurrence of zinc and iron ores in cavern-like structures.

"The field investigation indicated that the plane of this fault zone might reasonably be projected towards Mammoth Spring, Ark., and at this locality (Mammoth Spring) there is some evidence of an east-west fault, also the suggestion that the spring issues from this structural feature, or possibly from the place of intersection of the two faults.

"One of the most characteristic features of the West Plains area is that of broad, but very flat valleys in which there is no surface drainage except possibly that during periods of torrential rains. A study of the valleys and the knowledge of the fault plane, also the knowledge that solution has been an important factor in the geologic history of the region leads to the conclusion that the surface drainage is diverted into underground channels which, if controlled by the direction of the major fault zones, as it seems to be, would eventually issue forth as springs, and I believe in this case as one large one, Mammoth Spring. If this is true, and it seems perfectly plausible, Mammoth Spring will control the regional ground water level; a few small springs and seeps from openings above that level being excepted.

"(Mammoth Spring) on charts[1] plotted showing the static water elevations of wells from Willow Springs to Mammoth Spring, and hence the general surface profile, the depth and position of the Roubidoux and Gunter sandstones which will indicate the regional dip and the static water level in the wells and Mammoth Spring does exert a regional influence on the water table.

"– (Note) – – – – however the groundwater profile should be that of a flat arc, and would be higher at West Plains than at Mammoth."

The drainage area of Mammoth Spring is located north-east of the spring, and the Missouri Spring Factor for the drainage basin is 1.10. The effective drainage area for the spring is about 380 square miles.

1 Plate 7

Meramec Spring

Meramec Spring is located in sec. 1, T. 37 N., 6 W., 6 miles southeast of St. James, Phelps County. The water issues from a circular basin at the base of a rocky cliff, spreads and falls over the remains of an old rock dam, and flows swiftly down the spring branch 1 mile into Meramec River. The clear water bubbling from the basin and gushing over the falls and down the spring branch, combined with the pretty wooded valley and surrounding hills, make this a very beautiful place. The spring can be reached readily by driving from St. James. Although the place is private property, visitors are welcomed and some conveniences are provided for their use. Many people visit the spring each year.

Water power was formerly developed on the spring to serve a nearby iron mine and blast furnace. The remains of the large blast furnace and forge chimneys add to the romance of the location.

It is thought that the spring obtains most of its water from the bed of Dry Fork Creek and Norman Creek.

The very name "Dry Fork" suggests very little flow, yet the drainage area of Dry Fork is 425 square miles, or larger than the drainage area of the Meramec River above the junction of the two streams. On the numerous occasions that I have crossed Dry Fork, just above the junction, I would estimate the average flow was between 2 and 10 cubic feet per second. Norman Creek is a dry valley except after very heavy rains.

There are many cavern-like deposits of minerals directly south of the mine and these deposits tend to mark former solution channels, and show the trend of the drainage area of the spring.

The spring flows muddy after heavy rains, showing direct connection with surface drainage.

The Missouri Spring Factor is .88 and the effective drainage area is about 160 square miles.

Records of the daily flow have been collected from Dec. 1921 to Oct 1929, during this period the flow has been as follows:

	Date	Second-feet	Gallons per day
Maximum	1927, 1928	650	420,000,000
Minimum	Aug. 1, 1934	56	36, 200,000
Average		149	97,300,000

The average monthly and yearly flow in second-feet for hydraulic years ending September 30 is given in the following table:

Hydraulic Data for Meramec Spring

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Avg.
1922	–	–	167	119	127	225	309	164	116	115	103	98	–
1923	93	83	100	112	138	205	145	148	168	112	98	89	124
1924	80	78	145	95	133	128	145	154	233	225	169	132	143
1925	103	91	144	114	133	105	144	137	108	103	100	104	115
1926	113	139	117	84	145	165	178	120	91	82	80	80	116
1927	132	174	133	191	180	215	441	296	314	157	143	125	208
1928	174	275	300	152	158	188	299	188	239	153	149	118	199
1929	107	105	109	125	125	170	196	225	204	150	131	102	146
1930	106	–	–	–	–	–	–	–	–	–	–	–	–
Avg.	100	135	152	124	142	175	232	179	184	137	122	106	149

Table 11

Montauk Spring

Montauk Spring is located in $SE\frac{1}{4}$ sec. 22, T. 32 N., R. 7 W., a half-mile north of Montauk, Dent County. The spring has two main branches. The south branch has two mouths 300 feet apart in a gravel bar. The north branch has three mouths, one comes out of the rocks at the base of a hill and the other two out of the gravel at the foot of the hill. The two branches join near Montauk and the combined flow is used to operate a grist mill. The spring forms the beginning of Crooked Creek.[1]

The spring was visited on Feb. 27, 1938.

The author was able to locate only two of the five outlets mentioned above due to unfamiliarity with the spring.

The State has made a fish hatchery out of the spring and has thrown up dikes around the spring, raising the level of the pond about 8 feet or more. Possibly the other mouths were located in gravel bars in the bottom of the lake formed for the fish hatchery---or they may be across Pigeon Creek .

Two vigorous spring branches were noted across Pigeon Creek north of the two outlets that were located, and it is thought that these branches might be the spring branches carrying the water from the spring outlets that were not located. Lack of time prevented verification of this fact.

1 Beckman, H. C., Vol 20

The old grist mill has been repaired and remodeled by the C.C.C.

From themain lake the water flows over a small spillway constructed by the C.C.C. camp located in the State park. The crest of this spillway was estimated at about 15 feet (measured by stepping off the distance on the bridge just above the crest of the dam) the depth of the water over the crest was approximately .5 of a foot and the velocity was estimated at between 3 and 5 feet per second.

There are a number of 6" pipe installations supplying water to the various basins of the fish hatchery that discharges the water from the central lake to smaller lakes and these lakes in turn apparently discharge directly into Crooked Creek.

A marked lack of surface drainage in the plateau, above the spring, was noted. Great broad valleys would be almost entirely lacking in surface drainage of any kind, and most of the streams, that were seen, had only pools of water and then dry stretches. There had been much precipitation over this area during the two weeks preceding the inspection, and one would expect to find many flowing streams——yet this was not the case.

The major axis of the spring's probable drainage area lies to the north of the spring and the spring probably obtains much of its water from the basin of Pigeon Creek (also called Crooked Creek), and also from the large dry valleys to the north of the spring.

A rough check on the drainage area of Pigeon Creek shows approximately 50 square miles (traced on county highway maps of Dent and Texas Counties) much of the drainage area lies in the drainage area assigned to the Meramec River Basin.

Pigeon Creek was flowing at the time of the inspection. Measurements of the spring flow have been made as follows:

Date	Second-feet	Gallons per day
Oct. 2, 1923	63	40,700,000
Oct. 13, 1932	46	29,700,000
Aug. 13, 1934	38	24,500,000
Aug. 21, 1936	48.9	31,600,000

Round Spring

Round Spring is located in sec. 20, T. 30 N., R. 4 W., along State Highway No. 19, 10 miles north of Eminence, Shannon County. The spring rises in a circular basin about 80 feet in diameter surrounded by a rock wall 30 feet high. Then it flows through a cave for 80 feet, emerges at the foot of a small hill, and empties into Current River at a distance of 700 feet. It is the principal feature of the Round Spring State Park.

Spring Valley Creek is a dry creek bed most of the year, and has very little surface drainage except after very heavy rains on its water shed.

Bridge[1] states that it is most signigicant that a large spring is located at the mouth of this dry valley.

During February 1938 many of the rivers reached flood stage including the Current River (stage of 16.6 feet). The author passed over the bridge across Spring Valley Creek several times during the last part of February and in many places (at the shoals) the stream was less than 5 feet wide and had an estimated discharge of less than 10 c.f.s.

Sinking Creek having a slightly larger drainage area was flowing many times the quantity of water found in Spring Creek.

The spring's drainage lies in an area where the Missouri Spring Factor is 1.00 and the drainage area for the spring is about 40 square miles.

The spring is the smallest one on which daily records are kept, and since its drainage area is relatively small, the discharge is more readily affected by changes in atmospheric conditions. This spring would make an interesting study if an automatic water stage recorder and an automatic recording barometer were placed at the mouth of the spring, for it is believed that a sudden drop in barometric pressure at the mouth of the spring increases the discharge of the spring and this would account for the sensitiveness to change of the spring. A short study was made along this line---

1 Bridge, Josiah, Geol. of Eminence & Cardareva Quads. Mo. G. S. Sec. Series Vol. 24 page 36

using the iso-baric lines on the daily weather map as the barometric pressure at the spring, and the daily gage height of the spring. The greatest differential in pressure was about .4 of an inch of mercury corresponding to about .4 of a foot of water. The figures used were approximations and yet in many cases the spring showed an increased discharge when the barometer showed a decrease in pressure. If there were no direct opening between the surface and subsurface drainage the decrease in pressure would have the effect of creating a partial vacuum at the spring mouth and this would increase the flow of the spring until the underground pressure became equalized with the surface pressure.

Records of the flow of the spring have been collected from October 1928 to date. During this period the maximum and minimum flow recorded are as follows:

	Date	Second-feet	Gallons per day
Maximum	May 1933	520	336,000,000
Minimum	August 1934	12	7,760,000

The average monthly and yearly flow in second-feet for hydraulic years ending Sept. 30 is given in the following table:

Hydraulic data for Round Spring

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Avg.
1929	-	28.4	35.6	53.8	49.1	57.1	83.8	137	72.7	42.0	48.6	27.6	
1930	28.9	32.1	31.1	73.3	71.9	56.9	28.9	28.8	24.5	20.9	18.0	20.0	36.1
1931	31.9	20.9	25.2	19.3	38.4	67.2	28.3	39.7	27.1	20.0	27.3	19.7	32.0
1932	16.7	19.7	19.9	58.4	24.1	25.9	19.3	16.6	16.5	16.8	15.4	14.7	22.0
1933	21.1	23.0	55.4	64.4	24.4	28.9	95.7	166	37.6	23.0	22.2	19.7	48.7
1934	19.4	19.2	17.6	17.1	15.9	21.5	28.0	17.3	16.8	15.5	12.9	23.1	18.7
1935	17.3	19.7	26.6	35.2	19.9	149	53.6	51.3	166	83.3	35.1	24.5	57.0
1936	22.3	41.1	31.3	22.7	21.1	24.2	23.4	16.6	18.0	15.5	14.0	21.0	22.6
Avg.	22.5	25.5	30.3	43.0	33.1	53.8	45.1	59.2	47.4	29.6	24.2	20.2	36.2

Table 12

Welch Spring

Welch Spring is located in sec. 14, T. 31 N., R. 6 W., 3 miles southeast of Cedar Grove, Shannon County. The water flows out of a cave at the base of a rocky cliff. The water is divided by a small concrete dam near the outlet and one branch empties into the Current River after flowing about 100 feet. The other branch flows about 400 feet before entering the same river. The place is very picturesque but is rather difficult to reach by automobile.

The Missouri Spring factor is .93 c.f.s. per square mile.

The drainage basin is fan shaped and from a study of drainage, topograph and topographic road maps, and other data I believe that the spring's drainage area extends as far north as Salem, Mo. I believe that this spring is one of the main springs that gather water in the area assigned to the Meramec River Basin, and transports it underground, and finally empties the water into the Current River.

The effective drainage area is about 190 square miles.

Measurements of the flow have been made as follows:

Date	Second-feet	Gallons per day
Oct. 2, 1923	115	74,300,000
June 22, 1924	331	214,000,000
Oct. 14, 1932	77	49,800,000
Aug. 21, 1936	78	50,400,000

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